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ELEMENTS OF PHYSICS.

ELEMENTS

OF

HYSICS.

BY

C. F. PESCHEL,

AL OF THE ROYAL MILITARY COLLEGE AT DRESDEN,

ETC.

TRANSLATED FROM THE GERMAN,

WITH NOTES,

BY E. WEST.

Illustrated with Diagrams and Woodcuts.

PART I.

PONDERABLE BODIES.

NEW-YORK
NEW YORK PUBLIC LIBRARY

LONDON:
PRINTED FOR
AN, BROWN, GREEN, AND LONGMANS,
PATERNOSTER-ROW.
1845.

TRANSLATOR'S PREFACE.

The study of the physical sciences has become of l almost universal; partly because it has been found v suited to cultivate habits of observation and reasoni which cannot fail to be of use in the business of life, a partly because the practical application of scientific pr ciples to the details of almost every department of ma facturing and agricultural industry, has rendered so acquaintance with natural philosophy and chemistry ind pensable. Instruction in these branches of knowle now forms part of the education given to most boys school: to meet their requirements so many treatises h already been published, that to add to the number n seem a mark of presumption. To this objection translator was not altogether insensible whilst prepar the present Text-book for the press; he believes, howev that on examination it will be found that the man now offered to the public occupies ground not taken up any existing treatise on Natural Philosophy, for the wo on this science in our language are, almost without e ception, either purely theoretical, or they are, in the stric sense of the term, popular.

The present work is of a mixed character, bein systematic treatise, adapted for the use of schools, excl ing difficult mathematics, but retaining the mathemati method. It contains many numerical illustrations exercise the student in the application of the formu besides copious tables, which will give it a value to practical man. The foreign measures have, for the m part, been reduced to English standards, and a few no have been added to the original matter.

ce to the idioms of our own language,
in brackets the additions which he
r three instances to the original text.
to page 243., he has substituted the meth
and Littrow for the barometric mea
les for that of the author, which was b
l than theirs, and also too long for th
be afforded for it in the translation.
have been added, either explanatory of
e sake of giving the opinions of eminent
these have not altogether coincided wi
r advances.

e Second and concluding Part, containing
ponderable Bodies, is in preparation.

MERSHAM,
n. 27. 1845.

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INTRODUCTION.

The term Nature is used to signify the assemblage of all the bodies of the Universe; it includes, therefore, whatever exists and is the subject of change. Of the existence of these bodies we are rendered conscious by the impressions they produce on our senses; we are further aware that the condition of these bodies is subject to a variety of changes, whence we infer that external causes are in operation which bring about these alterations.

The object of *Physical Science* is, therefore, to investigate nature under these two aspects. That branch of it whose end is to discover what is characteristic of different bodies, in order to arrange or classify them, is called *Natural History*; the range, however, of this division must be understood as being limited to the changes which organised bodies undergo during life. That portion of natural science which is called *Physics* comprehends an enquiry into the causes which excite the changes that take place in the material world, and into the laws by which these changes are regulated.

All material bodies may be distributed into three principal classes, viz. *unorganised* (or inanimate), *organised* (or animated), and the *heavenly bodies* (or primary organisations).

The *unorganised* or *inanimate* bodies, as minerals, water, air, &c., form the lowest class, and are, so to speak, the substratum for the others. These bodies are acted on solely by forces external to themselves: they have no definite or periodical duration; nothing that can properly be termed life.

The *organised* or *animated* bodies are more or less perfect individuals, composed of different parts or *organs*, adapted to discharge certain appropriate functions. In consequence of an innate property peculiar to them, known as *vitality*, bodies of this class are constantly appropriating to themselves unorganised matter, changing its properties, and deriving, by means of this process, an increase in their bulk; they also possess the faculty of reproduction. These bodies retain only for a certain time this vital principle, by which they thus curiously combine unorganised matter with themselves; when life is extinct the whole process ceases,

of the second class; those of
nents, its ocean, its atmosphere, which
most vigorous action on each other, and
the most important. Perhaps, by s
culiar to these immense bodies, the C
to combine the original simple substance
ing variety of minerals, &c.; a process w
gether dissimilar from that which is c
bodies. It is generally admitted that the
for believing that the other planets and
similar to our earth, but that the fixed s
comets, bear to them a more remote rese
component parts of the latter are combine
differing from that of the former. These
haps be organised, though under forms o
properties extremely unlike those of animal
further be remarked, that the earth supports
the animal and vegetable world, and the re
have demonstrated, that there was once a
plants nor animals existed on this globe, and
creation of either of these orders, great change
place in the constitution of our earth. As the
anterior to the organised beings upon it, we
other heavenly bodies in like manner were called
any of the organised bodies, which probably
Reasoning, then, by analogy from our earth, we
regard the heavenly bodies as the *primary org*
whose surface both animals and vegetables
second class, find a place
Lastly

produced, and all those *external* changes which leave the substance of the body unaffected.

Chemistry, on the contrary, treats of the individual properties of bodies, by which, as regards their material constitution, they may be distinguished one from another; it also investigates the transformations which take place in the interior of a body, transformations by which the very substance of the body is altered and remodelled; and, lastly, its aim is to detect those laws by which chemical changes are regulated. That division of this science which has for its object the resolution of bodies, and the investigation of their elements, is called *analytical chemistry; synthetical chemistry*, on the contrary, by varied combinations of their elements, teaches us which are similar substances; and lastly, *stechiometry* shows the precision with which chemical combinations are formed in certain definite proportions by weight and volume.

Natural History is that branch of physical science which treats of organised bodies; it comprises three divisions, one *mechanical* — the anatomy or dissection of plants and animals; the second, *chemical* — animal and vegetable chemistry — and the third, *Physiology*, which is *explanatory*.

Astronomy, like all the other natural sciences, admits of subdivision into *theoretical, descriptive*, and *physical* astronomy; the first deduces the laws according to which the heavenly bodies move, the influence they exert on each other, &c.; the second describes the results of these discoveries; whilst the last applies to these bodies the general laws of physics.

Again, one most important use of natural science is the application of its laws either to technical purposes—*mechanics, technical chemistry, pharmacy*, &c. — to the phenomena of the heavenly bodies — *physical astronomy* — or to the various objects which present themselves to our notice at or near the surface of the earth — *physical geography, meteorology* — and we may add *geology* also, a science which has for its object to unfold the history of our planet from its formation to the present time.

Natural philosophy is a science of *observation* and *experiment*, for by these two modes we deduce the varied information we have acquired about material bodies: by the former we notice any changes that transpire in the condition or relations of any body as they spontaneously arise without interference on our part; whereas, in the performance of an experiment, we purposely alter the natural arrangement of things to bring about some particular condition that we desire. To accomplish this, we make use of appliances called *philosophical* or *chemical apparatus*, the proper use and application of which it is the office of *Experimental Physics* to teach.

If we notice that in winter water becomes converted into ice, we are said to make an observation: if, by means of

pace occupied by anot
rusting out the former.

Matter then is whatever occupies spa
and impenetrability; all bodies are mat

One might be led perhaps to imagi
longed only to solids, since we see th
and water; but on a closer observation a
demonstrated that this essential property
the above-named and to all similar bodies

First Exp. Fill with water a hol
a piston fits accurately — the piston
into the water, thus showing it to be

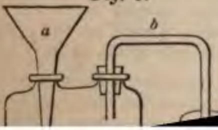
Second Exp. Invert a glass in wat
the air not being able to escape preve
fluid, and is thus proved to be an impe

One ingenious application of this
bell.

The difficulty of pouring liquor int
one small hole arises from the impen
the liquid can run into the vessel onl
escape. The following experiment wil

Third Exp. In one mouth (*a*) of
insert a fu
(*b*) a sip
of which
glass of w
be poure
and it

Fig. 1.



§ 3.

The non-essential properties of bodies are: *compressibility, expansibility, porosity, divisibility, elasticity, and gravity.*

Compressibility is that property of bodies by virtue of which they may be made to occupy a smaller space; and *expansibility* is that in consequence of which they may be made to fill a larger, without in either case altering the quantity of matter they contain.

Both these changes are produced in all bodies, as we shall see presently, by the action of heat; many bodies may also be reduced in bulk by other external causes, as pressure, percussion, &c. — Rolling, hammering, and stamping of metals.

§ 4.

Since all bodies admit of compression and expansion, it follows of necessity that there must be interstices between their minutest particles.

That property of matter, in consequence of which it does not completely fill the space bodies occupy, but leaves holes between their particles, is called *porosity*; these *pores* are themselves filled with other matter, commonly with atmospheric air. In many cases the pores are perceptible by the naked eye; in others, by the aid of the magnifying glass, and even when by this means they cannot be rendered visible, their existence may be inferred from experiments.

> Sponge, cork, wood, bread, &c., are bodies whose pores may be noticed by the naked eye. The human skin appears full of them when viewed through a magnifying glass: the porosity of water is shown by the ascent of air-bubbles when its temperature is raised.
>
> *Exp.* Pour some quicksilver into a piece of leather, press it, and there will be a fine metallic shower, proving the porosity of this animal substance.

The *mass* and *density* of bodies are estimated according to their various degrees of porosity. The mass represents the number of material particles in a body: the greater the mass, the less porous the substance will be. Density, on the contrary, expresses the relation of the masses when the volumes are equal: *i. e.* "*of two bodies that is the more dense, which with equal bulk contains the greater mass.*"

> 1) Let one body A have a density D and a mass M, and another body B of equal volume the density d, and the mass m; then $D : d :: M : m$.
>
> 2) Two bodies, A and B, whose volumes are V and v; then $D : d :: v : V$

divisibility of bodies is t
which, by various mechanical mea
grinding, &c., we can reduce the
each other, and to the entire ma
and so on.

The mathematical divisibility of
infinitum ; though its division, by m
limitation. Many examples, howeve
ried on to an incredible extent: we a
instances among natural objects, who
only by means of the most acute se
these with artificial aids; the size of
late only approximately.

1) *Mechanical subdivisions* for pu
arts, are *ex. gr.* the grinding of cor
phur, charcoal, and saltpetre, for
powder, &c.—Homæopathy afford
ably extended application of this p

2) *Divisibility of metals.* — Som
and silver, are susceptible of a v
the common gold lace, the silver t
posed is covered with gold so atte
contained in a foot of the thread
grain. An inch of such thread w
of a grain of gold; and if the inch
parts, each of which would b
the quantity of

power, will appear 500 times longer; and the gold covering it will be visible, having been divided into 3,600,000,000 parts, each of which exhibits all the characteristics of this metal, its colour, density, &c.

3) *Divisibility of colouring matter.* — Dyes are likewise susceptible of an incredible divisibility. With 1 grain of blue carmine 10 lbs. of water may be tinged blue. These 10 lbs. of water contain about 617,000 drops. Supposing now, that 100 particles of carmine are required in each drop to produce a uniform tint, it follows that this one grain of carmine has been subdivided 62 millions of times.

4) *Minuteness of organised bodies and parts of bodies.* — According to Biot, the thread by which a spider lets herself down is composed of more than 6000 single threads. The single threads of the silkworm are also of an extreme fineness.

Our blood, which appears like a uniform red mass, consists of small red globules swimming in a transparent fluid called serum. The diameter of one of these globules does not exceed the 4000th part of an inch; whence it follows that one drop of blood, such as would hang from the point of a needle, contains at least one million of these globules.

But more surprising than all is the microcosm of organised nature in the Infusoria, for a more exact acquaintance with which we are indebted to the unwearied researches of Ehrenberg. Of these creatures, which for the most part we can see only by the aid of the microscope, there exist many species so small that millions piled on each other would not equal a single grain of sand, and thousands might swim at once through the eye of the finest needle. The coats-of-mail and shells of these animalcules exist in such prodigious quantities on our earth that, according to Ehrenberg's investigations, pretty extensive strata of rocks, as, for instance, the smooth slate near Bilin, in Bohemia, consist almost entirely of them. By microscopic measurements 1 cubic line of this slate contains about 23 millions, and 1 cubic inch about 41,000 millions of these animals. As a cubic inch of this slate weighs 220 grains, 187 millions of these shells must go to a grain, each of which would consequently weigh about the $\frac{1}{187}$ millionth part of a grain. Conceive further that each of these animalcules, as microscopic investigations have proved, has his limbs, entrails, &c., the possibility vanishes of our forming the most remote conception of the dimensions of these organic forms.

5) *Divisibility of odorous matter.* — In cases where our finest instruments are unable to render us the least aid in estimating the minuteness of bodies, or the degree of subdivi-

and papers laid near
East Indies and back withou
now, how many particles of m
body every second, in order to
all directions, and you will b
and minuteness.

In like manner a single drop
in a spoon over a spirit-lamp,
fragrance for a length of time.

§ 6.

Elasticity is the name given to that p
of which, when their form is in any ma
of themselves, their original dimension
force which acted upon them is remove
their original form, even after it has
tion of some considerable force, whilst
small degrees. The degree of elasticit
against which a body shows itself per
various in different bodies; so also is t
ticity, *i. e.* the minimum force which is
manent change in the position of its co
a separation of them. If a force is app
a body's elasticity, either it is torn, or it
original form and volume. Perfectly e
trary, are such as resist the operation o
and however long-continued its action.

The following are a few

following pretty experiment illustrates this fact with regard to antimony and bismuth.

Second Exp. Place a little antimony and bismuth on a piece of charcoal, so that the mass when melted shall be about the size of a peppercorn; raise it by means of a blow-pipe to a white heat, and then turn the ball on a sheet of paper so folded as to have a raised edge all round. As soon as the liquid metal falls, it divides itself into many minute globules, which hop about upon the paper and continue visible for some time, as they cool but slowly; the points at which they strike the paper, and their course upon it, will be marked by black dots and lines.

The recoil of cannon-balls is owing to the elasticity of the iron and that of the bodies struck by them.

§ 7.

And lastly, *Gravity* is evidently a property common to all terrestrial bodies, since they constantly exhibit a tendency to approach the earth and its centre. In consequence of this tendency, all bodies, unless supported, fall to the surface of the earth, and if prevented by any other bodies from doing so, they exert a pressure on these latter.

This is one of the most important properties of terrestrial bodies, and the cause of many phenomena, of which a fuller explanation will be given presently.

II. PHYSICAL FORCES IN GENERAL.

§ 8.

Whatever we observe as causing a body to exist under certain conditions, or whatever changes any of its relations, is called *Force*.

The nature of these unseen causes we are ignorant of; we know of their existence only by the effects they produce, and with these we become acquainted solely through the medium of our senses. Hence whilst their operations are going on they appear to us always in connexion with something material, which, in one way or other, affects our senses.

§ 9.

We shall find, though not always upon a superficial inspection, that the approaching and receding of bodies, or their component parts, is the basis of all those results produced by the various *physical forces that come* under our notice. In other words,

influence throug
the masses of bodies in space :
Molecular attraction, and the latte
vitation.

§ 11.

There is yet one other modificatio
kind of transition from the effects of
cular attraction, viz. the attraction a
bodies on their surfaces, when they m
is spoken of as the attraction of *Cohesi*

III. OF MOLECULAR ATTRACT

§ 12.

The *Molecular attraction* of matter c
bodies by the immediate operation of
other. According to this explanation,
collection or *aggregate* of minute parti
are formed by the attractive and repulsive
at immeasurably small distances.

Two very different hypotheses have
the nature of matter, or the mode of
known as the *atomic* theory, the ot
founder of the former and earlier was
sidered the basis of all bodies to be e
differing in form and nat
persed

data, deriving their origin from the Deity as the First Cause, and consider their innate attractive and repulsive force as a necessary condition to their combination in bodies. The main features of this hypothesis are borrowed from Aristotle, inasmuch as he supposed the basis of all bodies to be the four elements known to the ancients, the particles of which, endued with certain powers, constituted bodies. — According to Ampère, all bodies consist of equal particles, and these again of molecules that up to a certain distance attract each other. Their distance from each other he supposed to b regulated by the intensity of the attractive and repulsive forces of their matter, partly by the repulsion arising from the undulations of an ether within them, and partly by the attraction which is directly as the mass and inversely as the square of the distance. And lastly, these molecules consist of atoms held together by their attractive and repulsive forces, the latter of which preponderates. To whatever body the molecules belong, they are invariably hard and polyedrons in figure. Mechanical force separates only the particles; the force generated by the undulations of the atoms may resolve the compound molecules into more simple ones; but chemical agents alone can still farther resolve these into atoms. According to Poisson, all ponderable bodies consist of extremely small molecules, combined by attraction with heat, electrical and magnetic matter. Very little heat exists in the interstices between the molecules, the greater quantity is therefore attached to them, for which reason the effects of the caloric seem to proceed immediately from them. The molecules attract each other and attract heat, whilst this last principle is repulsive to itself, and both forces diminish so rapidly as the distance of the molecules increases, that they become quite inappreciable at any distance that we can observe. The molecules, however, are so small that the distance, at which a diminution in the forces takes place, is always a multiple of its diameter, and consequently an incalculable number of such molecules is conflicting at the same time with each one of these forces. The two forces do not follow the same laws with regard to their decrease by distance: there is, however, a certain point at which a stable equilibrium obtains between them.

§ 13.

Consequently, according to this assumption, the molecular orces are the effective causes which hold together the particles f bodies. Through them the atoms (molecules) approach to a ertain distance, where they gain a fixed and unalterable position rith *respect to each other.*

...ction and rep

...e are three cases, viz. two extreme is that in which att atoms; this produces the *soli* prevails, and the *gaseous* form obtains when neither of these fo presents itself to us under the liq

Let A represent the attra the three aggregate forms ma formulæ:

$A > R$ s
$A < R$ g
$A = R$ li

These three forms or conditions part be readily distinguished by c there are, however, especially betwee imperceptible degrees of approxim difficult to decide where the one for It is further an ascertained fact that as for instance water, are capable of of aggregation.

Thus, supposing that the relativ forces determines these three form what has been said above, that this body.

The peculiar properties belonging be explained presently, when come severally und

IV. OF GRAVITATION IN GENERAL.

§ 15.

The *principal external forces*, viz. those of *gravitation*, are the result of the mutual action of the masses of bodies through intervening space.

A distinction is made between the gravitation of the celestial bodies, or *universal gravitation*, i. e. the phenomena arising from the mutual action of those large bodies on each other and the gravitation of our earth, or *terrestrial gravity*, i. e. the phenomena which must be attributed to the mutual operation of terrestrial objects; in other words, the effects which the earth produces on all bodies forming with itself one whole.

Both these species of gravitation are displayed in the approach and receding of bodies in space; or, expressing otherwise the same idea, they both generate *Motion*.

SECTION II.

I. OF MOTION IN GENERAL.

§ 16.

The *Motion* of any body is its change of place. *Rest*, on the contrary, is the state when a body occupies the same place. — Motion reigns throughout Nature, and probably absolute rest is nowhere to be found in the universe.

> *Apparent Motion and Rest.*—To a person on board a swift-sailing vessel, objects on shore seem to be moving in a direction contrary to that in which the ship is going; a similar appearance is presented by the trees on a road-side to a person travelling rapidly along the road.—The apparent motion of the sun and the apparent rest of the earth.

§ 17.

A cause must always exist for motion, as being an alteration in the state of a body (§ 8.); during the motion a certain time must necessarily elapse; and lastly, the moving body must pass over a certain distance in a definite direction, which will depend on the causes of its motion. The chief points to be regarded will therefore be —

Powers are eith

To the former class bel
they are gravity both unive

Secondary motive powers,
in their effects, as, *ex. gr.*, b
wind and water-mills — by e
force of expansion, as the co
the syringe of a fire-engine, &
the effects of steam, and gun
animal power, whether of men

For the best established
forces, see Table I.; the
furnish those of the pressu
upon heat will give informa

Forces, with regard to the dur
into momentary and permanent.
for an instant on the body set in m
continue in operation for some gi

Forces which act according to
whilst such as follow different law

All forces may be considere
measured by the effects they prod
either by numbers, or by lines pr

TAB

Of Anim

In order to

The Loads are supposed to be moved horizontally.	Load moved.	Velocity in		Day's work in Hours.	Useful Effect in 1 Sec.	Useful Effect in 1 Day
	lbs.	1 *Sec.*				
A man carrying no other burden than his own weight - - -	116	4·75	ft.	10	551	[illegible]
A soldier carrying 40 lbs., travelling 3 miles (almost 14 English) - -	136	4	—	5	[illegible]	[illegible]
A labourer, with loaded hand-barrow, returning empty - - -	60	1·64	—	10	98·56	[illegible]
Ditto, with wheelbarrow -	167	[illegible]	—	[illegible]	[illegible]	[illegible]
Ditto, with two-wheel truck	179	[illegible]	—	10	[illegible]	[illegible]
A cavalry-horse, with his rider and accoutrements, marching 3 miles (almost 14 English) - -	230	4·5	—	4·6	[illegible]	[illegible]
A horse, carrying his load at a foot-pace - -	214	3·48	—	10	744·72	[illegible]
Ditto, trotting - -	143	6·96	—	7	[illegible]	[illegible]
A horse, drawing a loaded cart at a foot-pace -	1250	3·48	—	10	4350	[illegible]
Ditto, drawing a waggon at a trot - - -	625	6·96	—	4·5	4350	[illegible]
The Load is supposed to be raised perpendicularly.						
A man, without load ascending a gentle slope, or mounting a staircase -	116	0·47	—	8	54·52	1,570,176
A workman throwing up earth with a shovel to a height of 5 feet - -	5	1·26	—	10	6·3	226,800
A labourer, wheeling loads in a barrow up a slope, whose inclination is one-twelfth, and returning empty - - -	107	0·06	—	10	6·42	231,120

A good pack-horse can at a foot-pace carry 180—260 lb. 15 or 16 English miles a day; at a trot he will carry 160 lb. 7—8 hours a day. The greatest momentary *draught-power* of a horse, according to Migout and Bergery, is 700 lb. as a mean: these authors estimate this animal as able to draw 130—140 lb. 9—10 hours daily with a velocity of 3·2. Navier says that a horse can draw a load of 600 lb., in a four-wheeled carriage on a level road, 28 miles in 4½ hours. On an average, even on a bad road, a horse can draw 3·7 as much as he can carry. When not over-loaded, a horse draws most advantageously when the trace makes an angle of 11° with the line of traction.

By the term *horse-power* is to be understood the effect by which 33,000 lb. could be raised 1 foot in a minute, or 550 lb. in a second.

The different points of
in different directions; this is
on an axis implies, in addition
parts of the body shall revolve
a state of rest, called the *axis*.
The wheels of any piec
motion round their axes; t
the earth, a rolling ball, the
are illustrations both of dire

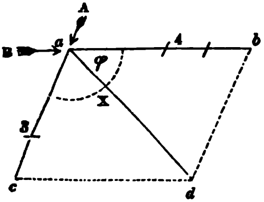
§ 2

That motion is called *simple* whic
force, but when several forces act t
so produced is said to be *compound*.
In any compound motion the mo
in three modes as regards their direc
1) The forces may either all act in
2) they may act in directly opposit
3) they may act at some angle.
Such a *single force* as is equivalent to
is called the *resultant*.
In the first of the above cases the resu
forces, and their direction remains unalte
the difference of the forces, and the direc
force. If the forces acting in opposite
neutralise each other, and

of the resultant, and also the distance which the point **a**, *if acted on simultaneously by the two forces, would pass over with uniform velocity, in the same time.* — The construction employed for discovering this resultant is called the *Parallelogram of Forces*, and the two original forces *ab*, *ac*, are called the *Components*.

The length and direction of the resultant may also be found by the aid of geometry and trigonometry.

Fig. 3.



Let the two components form a right angle (*fig.* 2.), then

$ad = \sqrt{ab^2 + ac^2}$, Eucl. I. 47.

or $R = \sqrt{B^2 + A^2}$

But if they form any other ∠ x (*fig.* 3.), then

$$ad = \sqrt{ab^2 + ac^2 - ab \,.\, ac. \cos. (180 - x)}$$

$$= \sqrt{ab^2 + ac^2 - 2ab \,.\, ac. \cos. x}$$

or $R = \sqrt{B^2 + A^2 - 2AB. \cos. x}$

Substituting ϕ for the ∠ *bad* formed by the component B with the resultant, then

$$\sin. \phi = \frac{A \sin. x}{R}, \text{ and}$$

$$\tan. \tfrac{1}{2} (2\,\phi - x) = \frac{B - A}{B + A} \tan. \tfrac{1}{2}\, x$$

By means of these formulæ, the amount and direction of the resultant may be determined from the two component forces.

Motions which obey the laws of the parallelogram of forces are, *ex. gr.*, the sailing of a vessel up a stream, ferrying across a river, the fall of a body from the mast-head of a ship as she sails, &c.

§ 24.

The Parallelogram of Forces serves —

1) For the *Composition of Forces, i. e.* instead of several forces acting in different directions on one point, to find a resultant. — The direction and velocity to be substituted for the motion compounded of the different forces is found, according to the preceding §, by obtaining the resultant for any two of these forces, from this and the third force compound a second resultant, and so proceed, till no more forces remain. The last diagonal, to which this construction leads, will give the direction and intensity of the resultant of all the *components*.

eter of the
called a *plumb-line*; the line
dicular; and a line or plane a
horizontal. At small distances,
the lines of gravity may be consi
account of the magnitude of th
greater distances where miles in
perpendiculars must be estimate
the earth's surface.

The convergence in one g
geog. miles it amounts to 1°.

§ 33.

Every body not supported, or
falls towards the surface of the earth
gravity.

As gravity is a force constantly in
of bodies, which is purely the result
uniformly accelerated motion.

Again, as gravity operates with
i. e. as every individual atom of a
wards the earth, *all bodies must fall*

In calculating this effect of gra
through in the 1*st second of time* s
whole distance through which it
space is 16$\frac{1}{10}$ feet.

The laws that regulate th
ledge of wh

2) *The spaces fallen through in equal successive portions of time in-
ase as the odd numbers* 1, 3, 5, 7, &c.

i. e. a falling body descends in the 2d second of its fall through 3 times, in the 3d second through 5 times the space passed over in the 1st second. Thus the space of the

$$
\begin{aligned}
&\text{1st sec.} = 1 \times 16\tfrac{1}{12} = 16\tfrac{1}{12}\text{ ft.}\\
&\text{2d} — = 3 \times 16\tfrac{1}{12} = 48\tfrac{1}{4}\\
&\text{3d} — = 5 \times 16\tfrac{1}{12} = 80\tfrac{5}{12}
\end{aligned}
$$

3) *The spaces, counted from the beginning of the fall, or the whole
aces fallen through, increase as the squares of the times, thus* 1^2, 2^2
, 4^2, &c., t^2 = 1, 4, 9, 16, &c.

i. e. a body in 2 seconds falls through 4 times, in 3 seconds through 9 times, in 4 seconds through 16 times the space it descends in 1 second. Thus it falls in

$$
\begin{aligned}
&1\text{ sec. } 1 \times 16\tfrac{1}{12} = 16\tfrac{1}{12}\text{ ft.}\\
&2 — 4 \times 16\tfrac{1}{12} = 64\tfrac{1}{3}\\
&3 — 9 \times 16\tfrac{1}{12} = 144\tfrac{3}{4}\\
&t — t^2 \times 16\tfrac{1}{12}
\end{aligned}
$$

4) *If a body were to continue in motion with the final velocity acquired after falling a given time, and the operation of gravity were to be then suspended, the body would descend in a time equal to that during which it had already fallen, with a uniform motion, through twice the distance of the first fall.*

The space fallen through in 3 seconds is = $144\frac{3}{4}$ ft., the final velocity of 3 seconds = $96\frac{1}{2}$. Now a body continuing to fall for 3 seconds with a uniform velocity would pass through a space of $3 \times 96\frac{1}{2} = 289\frac{1}{2} = 2 \times 144\frac{3}{4}$. The above laws were first published by Galileo in 1638.

The subjoined table expresses at one view the first three laws:—

Times - - -	1,	2,	3,	4,	5,	6,	etc.—t
The final velocities -	2,	4,	6,	8,	10,	12,	etc.—$2t$
The space for each time -	1,	3,	5,	7,	9,	11,	etc.—
The whole spaces -	1,	4,	9,	16,	25,	36,	etc.—t^2

Exp. Confirmation of these laws by Attwood's machine. Its application and principle.—If it be required in experiments on the descent of bodies that the descending weight should fall only 1 inch in the 1st second, instead of $16\frac{1}{12}$ ft. = 193 in. nearly, then the additional weight to be placed on it must be $\frac{1}{193}$ of the entire mass that is to be set in motion; or thus, let M represent the weight of the wheel, cord, and weights attached, p the additional weight to be added on one side, which being acted on by the gravitation of the earth, *sets the whole in* motion, g the distance a body would

Supposing $g' = 1$ inch, then $g =$
nearly.

1) In every uniformly accelerated
state of rest on beginning to move, h
that moment, however, it increases i
sion. Now let the velocity which a
falling during 1 sec. $= v$, then its n
sec. will be $\frac{0 + v}{2} = \frac{1}{2}v$, and the body
this mean velocity will traverse the s
which it would have fallen freely in
$= g$; or $\frac{1}{2}v \times 1 = g$, whence $v = 2g$ f
final velocity acquired by a body fal
double the space through which it has
as the space nearly, its velocity will be

In the 2d sec. the body continues
acquired velocity $v = 32$ ft. in consequ
(§ 27.), besides which gravity acts upon
accelerating its motion, so at the end of
have acquired a velocity of $2v = 64$ ft.
will have descended in the 2d sec. is equ
would have fallen with the mean velocity
and final velocities, that is, with the veloci
therefore $= 3 \times 16 = 48$ ft.

It is evident that after the lapse
of the body will

b) That the spaces fallen through in each successive second are in the order of the uneven numbers, for —

the space fallen in the 1st sec. $= 1g = 16$ ft.
- - 2d — $= 3g = 48$ —
- - 3d — $= 5g = 80$ —

Hence it follows, that —

c) The spaces are as the squares of the times, for —

in the 1st sec. the space $= \quad 1g = 1 \cdot 16 = 16$
— 2d $= 1g + 3g \quad = 4g = 4 \cdot 16 = 64$
— 3d $= 1g + 3g + 5g = 9g = 9 \cdot 16 = 144$

the whole distance fallen in t sec. $= gt^2$

Since a falling body after t seconds has acquired the velocity tv, it will, moving uniformly with this velocity, in the same time, t sec. fall through the space $t \cdot tv = t^2v$, and as $v = 2g$ this space must $= 2gt^2$, which is exactly twice the distance fallen in t sec., thus proving the 4th law.

Let h = the space, t = the time, v = the final velocity, and g = the space fallen through in the 1st sec., then we have the following equations deducible from the preceding laws: —

$$1)\ v = 2gt, \text{ whence } 2)\ t = \frac{v}{2g}$$

$$3)\ h = gt^2, \text{ whence } 4)\ t = \sqrt{\frac{h}{g}}$$

In like manner by substituting 2 in 3

$$5)\ h = g \cdot \frac{v^2}{4g^2} = \frac{v^2}{4g},$$

and in like manner substituting 4 in 1; we have

$$v = 2g\sqrt{\frac{h}{g}} = 2\sqrt{gh} = \sqrt{4gh}$$

The following are a few examples to be solved by the application of the above formulæ: —

1) The highest known mountain in the world, the Dhawalagiri in India, rises about 25,780 feet above the level of the sea; in how many seconds would a stone fall through that height? — By the 4th formula, $t = 40$ sec.

2) With what final velocity will the stone in the case supposed above reach the ground? — By the 1st form. $v =$ 1288 ft.

3) How long has that body been falling which comes to the ground with a final velocity of 322 ft.? — By the 2d form. $t = 10$ *sec.*

laws which = 258 f
exactly fulfilled, only if the m
One obstacle in constant ope
yet been considered, is the r
occasion of all bodies coming t
they would if falling *in vacuo*
the resistance offered by the a
more fully treated of hereafter.

1) That all bodies *in vac*
is demonstrated by the cote
and feather in what is genera
experiment, as performed wit

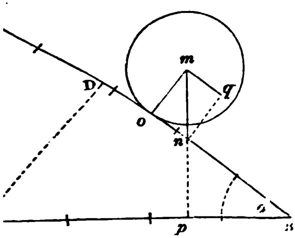
§ 34

Since our earth is not a perf
diameter less than its equatorial, it
it (irrespective of inequalities of the
same distance from its centre, and
(§ 29.) as well as by what was show
operations of gravity in general, the a
vary in different places; it will be w
strongest at the poles. The space th
in the 1st second of time at the poles i
equator it is only 16·016 ft.

Of the Descent of Bodies o

e amount of the pressure on the inclined plane is such a n of the absolute gravity or weight of the body, as the base of the plane is of its length; i. e. (see *fig.* 8.) the pressure would $= \frac{\text{BC}}{\text{AB}}$ or, *the pressure on the inclined plane is to the absolute weight of the body as its base is to its length*, i. e. *as* BC : AB.

Fig. 8.



Required the pressure exerted by a body, whose weight = 100 lb., on an inclined plane whose base is 6 ft. and length 8 ft. —— Ans. 75 lb.

The velocity in the first second of time is diminished in a scent of this kind in the ratio of the height to the length of e plane, or (*fig.* 8.) as AC : AB; *i.e. the accelerated motion of a dy descending an inclined plane, or its relative force of gravity, is that of a body falling freely as the height to the length.*

How many feet will a ball roll in 1 sec. down an inclined plane, whose length AB, *fig.* 8., = 160 ft., and whose height AC = 16 ft.? —— Ans. 1·6 ft.

The correctness of the two laws given above may be deduced from the following: — Let mp represent the line of direction, and $mn = k$, the weight (or absolute gravity) of the body, which exerts on the plane a pressure $mo = k'$, and a downward force (its relative gravity) $mq = on = k''$ (§ 26.), and the $\angle\, a$ the inclination of the plane to the horizon, then as the Δ s mno, BAC, are similar, we obtain the following proportions:

$$1)\; k : k' :: mn : mo :: \text{AB} : \text{BC} :: 1 : \cos.\, a$$

$$2)\; k : k'' :: mn : mq :: \text{AB} : \text{AC} :: 1 : \sin.\, a$$

The space k would fall freely in 1 sec., being $= g$ (§ 33.) that fallen by k'' or $g' = g.\ \sin.\, a$. In t seconds the body would descend upon the plane a space $h' = t^2 g\ \sin.\, a$, and would consequently acquire a final velocity of $2tg.\ \sin.\, a$. The space fallen freely in t sec. being $= g t^2$,

§ 36.

A body descending on an inclined plane
acquires a final velocity equal to that whic
supposing it to have fallen freely from th
plane.

1st. ex. gr. Let the base BC = 2
AC = $16\frac{1}{12}$ ft., and the length AB =
in descending the plane, will acquire
ft., which is the same that it would hav
perpendicularly $16\frac{1}{12}$ ft.

By the 6th formula in § 33., the
distance AC, fig. 8., will be $v = \sqrt{4g.}$
for the slant side AB, the final velocity
$= \sqrt{4g.\ \text{sin.}\ \alpha\ AB}$ (by the preceding §

Or thus, still referring to the same f

1) $v = 2\sqrt{gh}$; and

2) $v' = 2\sqrt{g'h'}$, but by the preceding

$$h : h' :: g : g'$$
$$:: AB : AC$$
$$:: h' : h;$$

$\therefore g' = \frac{gh}{h'}$; substituting this value in

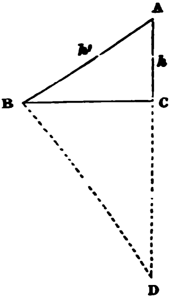
$$v' = 2\sqrt{\frac{gh}{h'}}, \text{ but } h' = 2\sqrt{gh}$$

In like manner the space passed throu
freely is to that gone over on the inclined pl

The space through which a body would fall by the action of gravity in the time that it would descend the whole length AB (*fig.* 9.) of the inclined plane, is found by letting fall a perpendicular at the point B to meet the height AC produced in D. AD will be the distance required: ∴

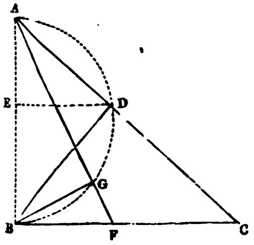
$$AD : AB :: AB : AC$$
$$:: h' : h$$

Fig. 9.

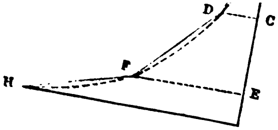


If it be required to determine geometrically what part of the length of an inclined plane a body will pass over whilst another body falls freely the height of the plane, it is merely necessary, as in *fig.* 10., to describe a semicircle on the height. The part AD, cut off by the circumference, is the distance sought; then join DB, and draw DE parallel to BC. Let there be a second inclined plane, ABF, of the same height AB, the body, would traverse the space AF in the same time that it would fall freely from A to B. Suppose now, that there were several such planes, all of the same height, AB, the chords BD, BG, being conceived to be parts of their inclined sides, we obtain the following law, first laid down by Galileo, *that all chords terminating in one extremity of the diameter of a circle, being considered as inclined planes, will be traversed by a body in the same time that it would have fallen by the action of gravity alone, through a space equal to the diameter*; *i. e.* in the time that a body would have fallen from A to B, it might descend from A to D, from A to G, from D to B, or from G to B.

Fig. 10.



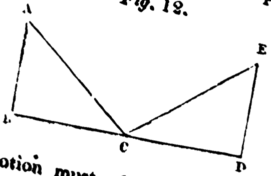
If several inclined planes be joined together, as is represented by the crooked line ADFH, *fig.* 11., a body that has traversed from A to D will have acquired the same velocity as it would have gained by falling perpendicularly from A to C; or if two bodies start from A with equal initial velocities, the one from A to G, and *the other in the direction* of the crooked line ADFH,



§ 37.

A body on arriving at the bottom
acquired a corresponding uniform m
in which it descended the plane it
to twice the length of the plane (a

Fig. 12.



fall
how
poin
fig. 1
of eq
sent it
to asc
with t
coming

motion must of necessity be uniformly
of gravity is opposed to the body's ascen
it is retarded exactly corresponds with t
previous descent. In this case the distanc
pass over in the same time cannot be tw
scent, but only equal to it; *i. e.* th
second plane to an
down the

Such a contrivance as the above would furnish us with an extremely simple perpetual motion, were it not for those impediments to motion that have not yet come under review, by which the force of the body would be gradually annihilated.

Of Projectiles.

§ 38.

There are two forces in operation on every body, by whatever means projected; viz. the projectile force, which is momentary, and gravity, whose action is permanent. The motion thus obtained must consequently be a compound one, the forces acting sometimes in the same vertical, sometimes in exactly opposite directions, and sometimes obliquely. Hence the following circumstances must be observed.

§ 39.

When the projectile force acts in the direction of gravity, the path of a body is the same as it would have described by falling freely, its accelerated motion being increased in each successive portion of time in proportion to the projectile force added.

Thus, suppose a body to be projected *downwards* with the velocity v, it will fall in t seconds a space $= vt + gt^2$.

§ 40.

If a body be thrown *vertically upwards*, its motion, on account of the counteracting influence of the force of gravity, will be *uniformly retarded*; for, if the projectile force only acted upon it, it would have a uniform motion, passing through equal spaces in equal times. The effect of the projectile force is, however, lessened every moment by the attraction of the earth acting on the ascending body, and that, too, in exactly the same ratio as it accelerates the descent of falling bodies. The laws regulating the fall of bodies in these cases obtain an inverse application. A body will therefore entirely lose its velocity after a certain time, and by virtue of the attraction of the earth it will return to its surface in just the same time that was occupied in its ascent.

A body thrown perpendicularly upwards will be attracted towards the earth in the first second of time with a force of $16\frac{1}{10}$ ft., in the second sec. $3 \times 16\frac{1}{10}$, in the third $5 \times 16\frac{1}{10}$, &c.; or in two seconds the force of gravity will be $4 \times 16\frac{1}{10}$, in three sec. $9 \times 16\frac{1}{10}$, &c. This will be more clearly illustrated in the following example:— Suppose a body to begin its ascent with an initial velocity of $160 = 10 \times 16$ ft.; neglecting fractional quantities, we shall find *that it moves,* reaches the ground in the san employed in accomplishing its asce to its initial velocity, and indeed at the velocity with which it descends ascended.

Or thus, expressing it in general te

Let a body ascend vertically with a action of gravity, it would pass in t this force would, however, in that time that it would accomplish only $vt-gt^2$ its velocity will $= v-2gt$; at the mo body is at rest on beginning its descen

$\therefore t=\frac{v}{2g}$.

To determine the height a body rises for t its equivalent $\frac{v}{2g}$ in the equation

$$v'=vt-gt^2=(v-g$$

and we shall have

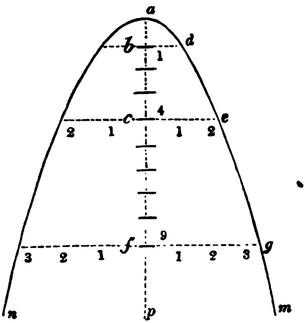
$$v'=(v-g\cdot\frac{v}{2g})\ \frac{v}{2g}=$$

The velocity which the body acquires $=2gt=2g\cdot\frac{v}{2g}=v$; *i. e. the body at t again the same velocity with which it was p*

If the time the body is in motio

unequal attraction of the earth; the course of the body will

Fig. 14.



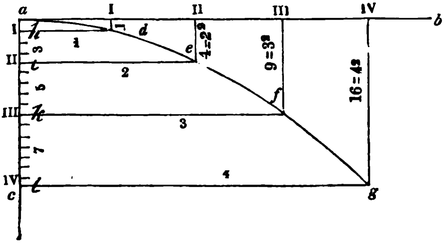
therefore be a curved line (§ 25.) named a *parabola*.

A parabola is a curve consisting of two similar sides *a m*, *a n*, which may be produced indefinitely, by being drawn in such a manner with regard to the axis *a p* passing through the vertex *a*, that the abscissæ *a b*, *a c*, *a f*, are to each other as the squares of the ordinates *b d*, *c e*, *f g*. Thus, if the former be 1, 4, 9, 16, &c. the latter will be 1, 2, 3, 4, &c.

§ 42.

a body be projected in a horizontal direction, its path will be *half* of a *parabola*, whose vertex *a* lies in the point of pro-on, *fig.* 15.

Fig. 15.



et *a b* represent the direction of the projectile force, and *a c* of gravity; a body *a* would be carried by the former force e in successive seconds of time through the equal spaces, *a*I, ., II.III, III.IV, whilst by gravity alone it would fall in essive seconds I, II, III, IV through the spaces 1, 3, 5, 7. 3.) If both forces act simultaneously on the body, it must, he law of the Parallelogram of Forces (§ 23.), arrive at the of the first second at *d*, at that of the second at *e*, of the third ; and of the *fourth at g.* Again, as gravity is not a force pro-

$ak : \quad kf ::$
$al : \quad lg :: 16 : 4$

From this figure we obtain also the

a) A body projected horizontally mo the projectile force, through a space e would have described had it been ac alone; but arrives at a point as much l it started as it would have reached hac same time.

b) A body descends towards the ea space that it would have fallen had i gravity only during the time of its r moment from the original perpendicu tion of the projectile force as this wo the same time.

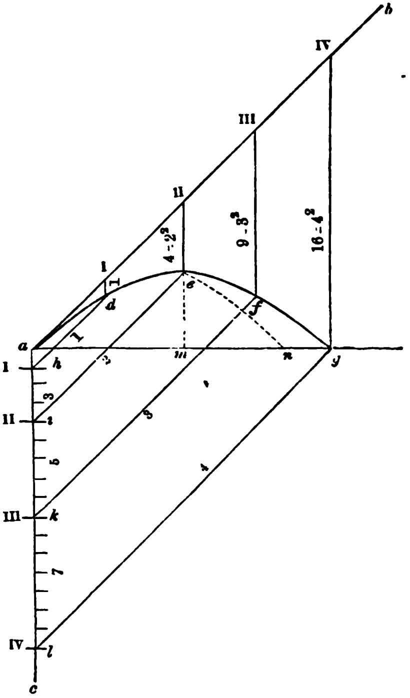
c) A body projected horizontally re actly the same time that it would hav same height.

§ 43.

If a body be thrown *obliquely upwards* its *parabola, a d e f g, fig.* 16., whose vertex *e* w reached by the body, which ascends one of scends the other *e f g*.

This path is obtained in the following body *a* were impelled in the direction *a b*, force alone acted on it, it would then arri I. in the second at II, in the third at II is, after the first second the body will have arrived at *d*, after econd at *e*, after the third at *f*, after the fourth at *g*, and so

Fig. 16.



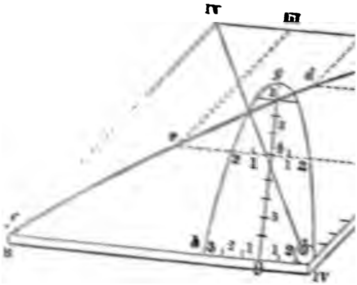
; in other words, it will move through the points *d*, *e*, *f*, *g*, king the curve *defg*, which, for similar reasons to those that re advanced in the case of a body projected horizontally, is a rabola.

In this curve the following proportions obtain :

Abscissa ah : its ordin. hd :: $1 : 1 :: 1^2 : 1$
— ai : — ie :: $4 : 2 :: 2^2 : 2$
— ak : — kf :: $9 : 3 :: 3^2 : 3$
— al : — lg :: $16 : 4 :: 4^2 : 4$

a projectio
colour, best of all of slate, A

Fig. 17.



any angle to the horizon; *a* and *b* is a ma
chalk kept in its place by a small groov
be struck so as to move horizontally, it
semi-parabola *a c d e f*; but if the ball *b* be
at any angle whatever, it will describe the

Of Motion round a Centre.

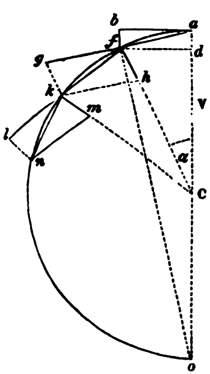
§ 44.

When two

tial *force*, by a momentary impulse, drives it in another direc-n, there will result a curvilinear motion round this point.

That the course of a body acted on by two forces, in the manner described above, must be curvilinear, may be deduced as follows: in *fig.* 18. let C be the centre of the attractive force, then suppose there to be a body at rest at *a*, unless supported it will fall towards C. Now let a force act on *a* in such a manner as to drive it from *a* to *b* in the same time that the centripetal force would have drawn it from *a* to *d*, it must in this time travel the distance *af*. In consequence of the body's inertia (§ 27.), in the next equal portion of time it will pass over *fg* = *af*, but the centripetal force meanwhile atttracts it to *h*; it will therefore arrive at *k*. In the third space of time the two forces will carry it, the one from *k* to *l*, where *kl* = *fk*, and the other from *k* to *m*; consequently it must pass over the distance *kn*, and so on. As the attractive force acts without intermission, the portions of time when its action may be considered to be renewed, must be regarded as infinitely small, and, consequently, as in projectile motion, the crooked line *afkn*, which represents the distance passed over, becomes a curve.

Fig. 18.



Such is the motion of the celestial bodies around their centres, the planets around the sun, and the satellites around their respective primaries. Universal gravitation acts throughout the creation as the centripetal force, and a tangential force must be assumed to have acted on these bodies imparted to them by their Maker.

As the result of the tangential force every body moving round centre acquires a tendency to fly off from that centre; this tenency is called the *Centrifugal force*. It is the antagonist of the Centripetal force, to which it sets limits.

Fig. 18. shows that after the first period the body, if under the influence of the tangential force only, would arrive at *b*, and that it would thus have receded the distance *bf* from the centre of motion C; *bf* is therefore the measure of the centrifugal force for that time. And since the centripetal force is opposed to the centrifugal, it compels the body to deviate from *a to f, instead of* proceeding from *a* to b.

If, on the contrary, the centrifugal force at ev body's path be inversely as the square of its di centre, it may be proved mathematically that t ellipse, in which case the velocity at one time i another decreases. The motions of all the plan performed in elliptical orbits.

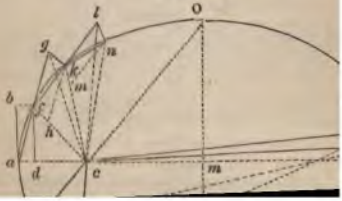
1) Referring to *fig.* 18., if we assume ab to quantity, ab may be considered $= df$, whence *when a body moves in a circular orbit, the cent fugal force is to the tangential, as the co-vers. sin. arc moved through.* If, then, we put $ad = P$, ab or $df = C$ the tangential force, and α, the at the centre of the arc af, then we have

$$ad : df$$

$$\text{or } P : C :: \text{co-vers. sin. } \alpha : \text{sin. } \alpha.$$

2) In an elliptical orbit the centre of the forc in one of the foci c of the ellipse *fig.* 19. All ri

Fig. 19.



and at some other point cr, which is its greatest distance, or the *Aphelion* of the planets, whence co is the *mean distance*.

3) If, as in *fig.* 19., in equal times $af = fg$,

$$\text{then } \Delta\, afc = \Delta\, fgc, \text{ Eucl. I. 38.}$$
$$\text{and } \because\ gk \text{ is parallel to } cf$$
$$\Delta fck = \Delta fgc$$
$$\therefore\ \Delta\, afc \doteq \Delta\, fck$$

In like manner it may be proved that the triangle fck = triangle kcn, &c.
Whence, *in an elliptical orbit equal areas are described by a radius vector in equal times.*

In n time we shall have n area, and in m time the m area; wherefore these areas are proportional to the times.

4) If the body a continue to be at an equal distance from c, as in a circular orbit, then the lines ca, cf, ck, &c.; and the chords af, fk, kn, &c. are equal, *i. e.* the velocity of the moving body is the same at every point of its orbit, or in other words, the body has a uniform motion; in an elliptical orbit, on the other hand, the velocities (ts, pq, *fig.* 19.) vary; whence planets move most rapidly at their perihelion and most slowly at their aphelion. — Mean velocity.

5) Suppose a body a, *fig.* 18, to describe the arc af in one second of time, then its velocity $V = af$, and if we assume af to be very small, the chord af will be so too. Then, since the triangles adf, afo in a circle are similar,

$$ad : af :: af : ao$$
$$\text{or } ad = \frac{af^2}{ao}$$

Here ad represents the centripetal force, or that motion caused by the action of gravity, as well as the centrifugal force. Again, substituting for it G, for the velocity af, V, and for the diameter $ao = 2R$, it follows: —

$$G = \frac{V^2}{2R}$$

Giving to g, v, and x corresponding values for any other point v,

$$g = \frac{v^2}{2r}$$

i. e. the centripetal and centrifugal forces are as the squares of the velocities, divided by the diameter of the circles described;

$$\text{or } G : g :: \frac{V^2}{2R} : \frac{v^2}{2r}$$

centre ; thence

$$G : g :: r^2 :$$

preceding, $G : g :: \frac{V^2}{2\,R} :$

$$\frac{V^2}{2\,R} : \frac{v^2}{2\,r} :: r^2 : R$$

$$\text{or } V^2 : v^2 :: r : R,$$

i. e. the squares of the velocities are

7) If the times employed by *a* their circles be called T and *t*, it fo

$$V\,.\,T = 2\,R\,\pi,$$
$$\text{and } v\,.\,t = 2\,r\,\pi,$$
$$\therefore V^2\,T^2 : v^2\,t^2 :: R^2 :$$

Dividing these proportionals by t obtain

$$\frac{V^2\,T^2}{V^2} : \frac{v^2\,t^2}{v^2} :: \frac{R^2}{r}$$

$$\text{or } T^2 : t^2 :: R^3 :$$

i. e. the squares of the times are to ea distances.

Keppler (1571—1630) deduced t from observations made by himsel earth and the other planets around th established on mathematical to his laws of pulley *k*, which is made to move with but little friction, and below the axis of two small parallel pulleys, *k'*. At the two extremities of the bar are the supports *ff*, in which the polished metal rod *ff* is secured, on which the wooden ball *g* may slide freely, a hole being drilled through it. The ends of a fine silk cord are fastened to small staples on opposite sides of the ball *g*, which cord runs singly over the small wheels *k'*, but double over *k*. A hook carrying the weight *h* is attached to this cord. This weight *h* consists of several parallel circular plates of metal of equal weights, that can be placed one on the other as may be required, and is intended to represent the force of attraction.

If, now, this apparatus be set in motion by the fly-wheel, *fig.* 7., the ball *g* will fly from the centre, tighten the cord, and raise the weight *h*, as soon as the centrifugal force of the ball has acquired a sufficient intensity. With a little practice so uniform a motion may be imparted to the wheel that the weight *h* shall be kept suspended above the rod *ff*. For instance, if the distance of the ball from the centre of rotation be 15 inches, and the weight $h = \frac{4}{8}$ lb., by performing a certain number of revolutions, about 40 in a minute, we shall be able to balance the weight. Repeat the experiment, the distance being 10 inches, and $h = \frac{9}{8}$ lb., 73 or 74 revolutions per minute will be required to counterpoise the weight *h*. Now, since

$R : r :: 3 : 2$ (§ 29.),

and $R^2 : r^2 :: 9 : 4$,

the squares of the distances are inversely as the weights; it follows also that

$R^3 : r^3 :: 74^2 : 40^2$,

which is actually the case in the numbers we have assumed, and thus the practice accords with the theory. The ball *g* has therefore on a small scale fulfilled the same laws as to the times of its revolution as the planets at their vast distances from the sun.

§ 46.

If a solid body of a spherical form revolve about an axis § 22.), all parts of its surface and mass will perform the revolution in the same time. Their velocities will therefore be as their perpendicular distances from the axis, *i. e.* as their radii, and consequently the centrifugal forces of the points will be directly as their radii. (Obs. 6. § 45.) The farther, therefore, the points are situated from the axis of rotation, the greater will be their tendency to fly off from it.

These particles then are in a state of *central motion*, such that the *centripetal force is* counteracted by the cohesive, and the

§ 49.

That force by means of which bodies, whether similar, adhere together, when their surfaces come called *Adhesion*. (§ 11.)

It has been remarked above, that this force doe equal intensity on all matter; that its operations not merely by the mass of bodies, but also by the nu of contact, or the extent of their touching surfaces; son it is sometimes called *Superficial Attraction*, effects obtain equally *in vacuo*, so that it must be the atmospheric pressure.

§ 50.

The adhesion between solids is best exhibited w ing surfaces are as smooth as possible. A certain site in such cases to separate the sides that are in c

First Exp. Two polished plates of glass *adhesion-plates*, will be found to stick together the other and slightly pressed.

Second Exp. Two plates of common wind like manner on each other do not adhere. the cause of this?

The intensity of the adhesive force may suspending one of the plates to the arm of a taching weights to the other arm until the plat Dividing now the weight thus found by the n inches in one plate, the quotient will give th for one square inch.

§ 51.

Adhesion obtains further betwixt solids and liquids. Two pposite conditions demand notice: either the adhesion is stronger an the cohesive force of the liquid (§ 13.), and the solid bemes moistened, or else the latter force exceeds the former, and n that case the solid is not wetted.

First Exp. Many organised and unorganised bodies become wet on being brought into contact with water, spirit of wine, and many other liquids — the human body, clothes, &c. if exposed to rain.

Second Exp. A drop of any of these fluids placed on a wooden table, or on a plate of glass, loses its globular form, and spreads itself over the surface of the solid.

This does not happen with a drop of mercury.

Third Exp. Immerse a finger in water, it becomes wet; in quicksilver it remains dry.

Fourth Exp. A tallow candle, or a feather of any species of water-fowl, continues dry, though dipped in water.

Fifth Exp. Gold, silver, tin, lead, &c. become moist on being immersed in quicksilver, but iron and platinum do not.

Sixth Exp. Quicksilver poured into gauze will not run through, water will. Let the gauze containing the quicksilver touch the surface of the water in a glass, and the metal will immediately flow through.

Seventh Exp. *Vera's Cord-pump* — an endless cord, running round two wheels, descends below the surface of the water, which it raises, by means of the adhesion subsisting between the liquid and the rope, to which a rapid motion is imparted by the upper wheel.

On this effect of adhesion depend writing with ink, Indian-ink, and colour drawing, the smearing of metals, especially iron, with oil or grease, to protect them from rust.

The measure of the absolute force of adhesion between solids and liquids is found, in the same manner as that of solids only, by the help of a balance, the solid being suspended, so that its surface just touches the surface of the fluid.

Even those fluids which do not moisten the solids immersed in em have yet a feeble degree of adhesion to them.

Eighth Exp. Small globules of mercury continue hanging to glass, paper, and other bodies, which they do not wet, even though held in such a position that they would naturally fall.

In many of these cases, namely, those in which the solid on coming in *contact with a liquid*, itself passes into the latter state,

this property if covered with any matter
that particular fluid.

First Exp. A glass bottle, or one made of
or well coated with dust, or with *semen lycop*
no moisture on being plunged in water — sph
water roll off its surface.

Second Exp. Put a ring or coin into a cup
the surface of the fluid with *semen lycopodii,*
can be picked out of the cup without wetting

On the circumstance of the solid's attracting moi
liquid, or not, as well as on the various degrees of
force, several other facts depend, as may be shown
ing experiments : —

Third Exp. Place a drop of water at the u
glass tube held in a slanting direction, its adhes
it to stick to the glass, whilst it descends to
tremity of the tube in consequence of the actio
on arriving at this point it assumes a globular fo
off as soon as the attraction of the earth has
adhesion. To this property we are to attribu
fluids running down the sides of the vessel con
when poured out of one vessel into another
form for drains, &c.

Fourth Exp. Smear part of the rim of a g
water with some hog's-lard, and then cover it
copodii. If the liquid be poured out over t
vessel it will run straight down, and not over
glass. — *Query.* Why so?

Fifth Exp. Quicksilver poured out of a g

Seventh Exp. Let a drop of water fall on a plate of glass, it will be displaced by a drop of oil of turpentine, which in its turn will give way to a drop of æther or spirits of wine. — It follows from this experiment that oil of turpentine has a stronger adhesion to glass than water has, and that æther has an adhesion stronger even than the oil.

§ 53.

The adhesive force between solids is materially increased by introducing a fluid between the surfaces in contact. The fluid fills up the existing inequalities, thus increasing the number of points of contact, for the adhesion is increased in a degree equal to the adhesion of the fluid body to the two surfaces of the solids.

First Exp. Two plates of common window glass on being wetted exhibit this property in such a manner as to stick tightly together.

Second Exp. Metal or glass adhesion-plates adhere together with far greater tenacity, if breathed on previously to their being brought in contact.

The Adhesion becomes Cohesion when the liquid thus introduced changes into a solid. Hence the application for various purposes connected with the arts, of glue, cement, and solder, the process of plating, that of silvering mirrors, and the use of mortar in building.

Third Exp. A thin flake of melted tallow introduced between the plates increases their adhesion: if allowed to become cold, it requires considerable force to sever them.

§ 54.

A remarkable instance of the effects of adhesion between solids and liquids is afforded in *Capillary Attraction* and *Repulsion.*

This peculiarity consists in the fluid's either ascending the solid body that touches it, or else descending to a lower level at the point of contact with the solid, being depressed by it. The attraction takes place when the solid is of a nature to be wetted by the fluid: repulsion occurs when this is not the case.

These phenomena are most observable in the interior of glass tubes of small bore, hence called *Capillary tubes;* and the narrower the bore the greater the effect produced. They contribute much to our acquaintance with the causes of this attraction and repulsion, inasmuch as the results are more easily noticed by us in these tubes than in bodies of any other form.

First Exp. Plunge the ends of several capillary tubes of various bores in water, the fluid will rise in the interior of the tubes to a height exceeding that of the surrounding water, the respective heights reached varying as the bores.

within the tube has become concave, its eleva
flows together, in consequence of the attractive
within the narrow limits of the capillary tube,
of particles in their turn acts upon the eleva
the fluid, when a second ascent of the bound
place, and a second confluence of the eleva
whilst the lower ones are lifted also by their
the upper. The action of these attractive for
till an equilibrium is established between the
column and its cohesion and the capillary att
tube.

Second Exp. Now insert the same tubes i
and the surface of the fluid within will be de
that of the surrounding fluid; its figure will b
its depth will increase as the tube is of narrowe

The depression of the mercury in this cas
counted for on grounds similar to those tak
planation of the preceding experiment. Tha
sinks as much below its original level as w
depressed column of liquid into equilibrium w
lary repulsion.

In tubes of the same material, the fluid a
same, the height to which it ascends, or the
sinks, will be inversely as the diameters of the b
inner diameters of two tubes be *d* and D, the
the attractions of the first tube is to that of
the diameters or circumferences of the tubes,
The attractive forces, however, are as the effe

It is evident that the height to which the fluid is raised or the depth to which it is depressed must depend on its specific gravity as well as on the tube, and that it will be affected by the temperature of the fluid. The heights therefore vary directly as the attractions, and inversely as the specific gravity; whence it follows that h × spec. grav. = attract. force.

The following phenomena likewise depend on the above-named rinciples :—

Third Exp. Dip a glass rod in any fluid that will adhere to it; water for instance, in consequence of its attraction to the rod it will ascend it for some distance.

Fourth Exp. Smear the glass rod with fat, or sprinkle it with *semen lycopodii,* and immerse it in water; in consequence of the repulsion around the rod, the water about it will descend to a lower level.

Fifth Exp. Plunge a clean glass rod in quicksilver; in consequence of the repulsion the latter will sink about the rod.

Sixth Exp. Dip a piece of polished tin in quicksilver; by virtue of its attraction the metal will ascend the tin.

Seventh Exp. Pour any adhesive liquid, as water, into a glass, and it will assume a concave form of surface by ascending the sides of the vessel.

Eighth Exp. Draw a ring of fat within the glass, and sprinkle it with *semen lycopodii;* the water will rise to the height of this circle, and, if still more be poured in, it will rise in a convex shape, that portion around the glass being depressed.

Ninth Exp. Quicksilver in a glass vessel assumes a convex form, and in one of tin a concave.

Tenth Exp. If two plates of glass be placed with one end of each touching the other, their sides being at a small distance asunder, and be thus immersed in any adhesive fluid, it will rise between them, and the highest point will be where the plates are nearest together.

Many natural phenomena are attributable to capillary attraction, as the dampness of the ground, sand, sugar, and other similar bodies below which any moisture exists; the ascent of oil, melted tallow, or wax, as well as that of spirits of wine in the wicks of candles and lamps, the absorption of fluids by sponge, blotting-paper, &c., the swelling of wood with change of weather, and the filtering of liquids through any porous vessels that may contain them. The ascent of the

---

Exp. 10. If the two plates be so placed at an angle with each other, that their vertical sides shall coincide, on being immersed in water or any other adhesive fluid, it will ascend between them, and form a *hyperbola.* — See *Playfair's Outlines of Nat. Phil. vol. i. p. 187.*

hours a portion of the water will penetrate to
whilst a still smaller quantity of the latt
escape. By this means the covering of the
so strained, that on its being punctured w
will be thrown several feet high. — The asce
is caused partly by capillary attraction, a
chemical affinity of the two fluids, whilst
tration of the other is due to the less power
ercised by the capillary tubes of the bladd
The spirit of wine being more strongly a
tubes, will flow out less readily.

The prodigious effects the application
large scale is calculated to produce, may be
ting large blocks of stone by the insertion of
wood which are then well saturated with w

§ 55.

The adhesive force between solids and liqui
motion in the former, provided they are light en
moved. Attraction takes place between solid bo
fluid on which they float adheres to them or n
the contrary, happens only when the fluid adhe
solids and not to the other.

First Exp. Lay a small hollow glass sphe
of some water contained in a glass vessel. —
being the movable solid, will gradually app
the vessel, to which it will at length be dra

globules when one has water adhering to it, and the other has not.

§ 56.

Adhesion obtains likewise between liquids, when one of two nditions will result; either the adhesion of the fluids will exed their cohesion or be less than it.

In the former case a perfect union will take place between the ids. If the forces be equal, when contact is established, adsion will immediately be converted into cohesion, and a homoneous mass will be obtained. When the forces are unequal, it frequently difficult to determine whether the union which relts is a chemical combination or merely a mixture.

In the second case it is merely the surfaces of the fluids which uch without uniting; that fluid whose cohesion is cancelled by hesion remains on the surface of the other.

First Exp. Two drops of the same fluid unite in one as soon as a contact is established between them.—This is most clearly shown in the case of two globules of mercury.

Second Exp. Water, wine, spirit, milk, and several other liquids, mix when poured together. The effects of their mutual attractions are therefore stronger than the cohesion of their respective particles.

Third Exp. Water and quicksilver, or water and oil, if poured together, will not mix. — The cohesion of the quicksilver or of the oil is consequently stronger than its adhesion to the water.

Fourth Exp. Let a drop of water fall upon some quicksilver, and it will spread itself over the entire surface of the metal. A similar result would follow if a drop of sweet oil be put on water, which will be overspread with a thin film, reflecting the prismatic colours.

Fifth Exp. Place a drop of liver of sulphur (tersulphuret of potassium) on the surface of some water previously covered with a film of oil, and it will take the place of the oil.

Here is presented to us the phenomenon of one fluid taking the place of another, even after the adhesive force of the one is stronger or weaker than that of the other. (§ 52.)

§ 57.

Lastly, adhesive attraction is displayed by aëriform bodies towards both solids and fluids, and is then distinguished by the name of *Absorption*. In these cases, Absorption seems frequently to be the first evidence of chemical attraction; for when gases and liquids unite it is often difficult to determine whether chemical combination *has or has not* taken place.

valents, and that part of chemistry which treats c which these numbers are determined and applied, *chiometry*, or the *doctrine of chemical Proportions.*

In the table, p. 64., the equivalents are oxygen = 100, and for hydrogen = 1, opposit the elements.

§ 64.

Many elements combine not only in that partic expressed by the numbers of the equivalents co table, but even unite with other elements in 2, 3, proportions.

By comparing these various proportions, it has that the proportion of that element which admit always an exact multiple of the simple equivalen compounds obey the two following laws, since eit

A single proportion of one element combines proportions of the other, or

Two proportions of the one combine with 3, 5 of the other

Thus not only simple substances, but also t combine only in definite proportions. This either by direct experiment, or by adding the a their constituent parts. If the equivalents whi elements constituting any body be added togeth the proportion in which this body will combine

Ex. gr. Potassa consists of 1 element of Po

Water consists of 2 elements of *Hydrogen* and 1 of *Oxygen*, whence the equivalent for *Water* is

$$= 2 \cdot 6 + 100 = 112$$
$$\text{or} = 2 \cdot 1 + 16 = 18$$

§ 65.

In exhibiting the composition of chemical combinations in a simple and intelligible manner, as *Chemical Formulæ*, the simple substances are represented by the initial letters of their Latin names, and if two or more elements begin with the same letter, a second is added.

One equivalent of a simple substance is expressed by writing merely the chemical symbol thus, 1 equivalent of *Potassium* = K. — Several equivalents are represented by the addition of a small cipher above or below the symbol, thus 5 equivalents of *Oxygen* = O^5 or O_5. It is customary to express 2 measures by drawing a line either through or beneath the symbol, thus 2 equivalents of *Nitrogen* = $\cancel{N}$ or $\underline{N}$.

The combinations of the first order, or of the elements with each other in pairs, are represented by writing their equivalents after the chemical symbols. — As oxygen and sulphur are so frequently combined with the other simple substances, an abridged mode of representing them is adopted, and for every equivalent of oxygen a *dot* is placed over the symbol of that body with which it is united, and for each equivalent of sulphur a *comma* is used; for 2, 3, 4, *etc.* equivalents, a corresponding number of *dots* or *commas* is employed.

Ex. gr., *Potassa* = $KO = \dot{K}$
Carbonic Acid = $CO^2 = \ddot{C}$
Water = $H^2O = \dot{\cancel{H}}$ or $\dot{\underline{H}}$
Sulphuret of Potassium = $KS = \overset{,}{K}$

Several equivalents of similar combinations of the first order are represented by a coefficient prefixed to the formula, thus

3 equivalents of *Carbonic Acid* = $3\,\ddot{C}$

The chemical formulæ for the combinations of the second order, the double pairs, are constructed by writing together the formulæ of the pairs composing them; thus

Nitrate of Potassa = 1 *Potassa* + 1 *Nitric Acid*

$$= \dot{K}\,\overset{\cdot\cdot\cdot\cdot\cdot}{\cancel{N}} \text{ or } \dot{K}\ \overset{\cdot\cdot\cdot\cdot\cdot}{\underline{N}}$$

Combinations of the third order, those of double pairs with each other, as also mixtures, are represented by writing the formulæ joining them *together* by the sign + thus

1 Sulphur
3 Carbon

$= \dot{K}\,\overset{\cdot\cdot\cdot\cdot\cdot}{\underline{N}} + S + 3\,C.$

§ 66.

The binary compounds, or chemical combina order, are commonly named and classified acco metallic substance they contain. Hence, they a as compounds of oxygen, or *Oxides;* of chlori of sulphur, or *Sulphurets;* of Phosphorus, or *Carburets*, &c.

The nomenclature of compounds of this class that the name of the class precedes that of the si

Ex. gr., Oxide of Iron, Oxide of Copper, O
Chloride of Iron, Sulphuret of Iron, Carbu

Combinations of the metals with each other ar *Alloys*, those of quicksilver with any other n *Amalgams*, as amalgam of gold, amalgam of si tin, &c.

Bronze is an alloy of copper and tin;
Brass of copper and zinc.

Combinations of this order, considered gener inorganic and of organic nature, differ widely chemical affinity. The former, in which the bine chemically and produce binary formati are called *Acids* and *Bases*, all others are term *binations*.

Most acids consist of combinations of non-metallic bodies; some, however, consist of one such body and a metal.

Inorganic Chemistry embraces such *Oxygen acids as have a simple radical;* they are chiefly binary compounds of oxygen with a non-metallic substance; a few only have a metallic base, and are hence called *metallic-acids.*

The following are given as instances of oxygen acids, viz.

Sulphuric Acid, compounded of 1 sulphur and 3 oxygen $= \dddot{S}$.

Carbonic Acid, comp. of 1 carbon and 2 oxygen $= \ddot{C}$

The following are *Metallic acids,* viz.

Arsenic Acid, comp. of 2 arsenic and 5 oxygen $= \overset{\cdot\cdot\cdot\cdot\cdot}{\underline{As}}$.

Antimonic Acid, comp. of 2 antimony and 5 oxygen $= \overset{\cdot\cdot\cdot\cdot\cdot}{\underline{Sb}}$.

Acids having a compound radical are nearly all of organic origin. They are either *Vegetable* acids, which are free from nitrogen, or *Animal* acids, into whose composition this element enters. The base or radical of the former is composed of carbon and hydrogen, that of the latter invariably contains nitrogen.

Two instances are given below of vegetable and one of animal acids, viz.

Acetic Acid, comp. of 4 carbon, 6 hydrogen, and 3 oxygen $= C^4\ H^6\ O^3$.

Gallic Acid, comp. of 7 carbon, 2 hydrogen, and 3 oxygen $= C^7\ H^2\ O^3$.

Cyanic Acid, comp. of 2 carbon, 2 nitrogen, and 1 oxygen $= C^2\ N^2\ O$.

In the class of acids which has just been noticed the characteristic element was oxygen; there is another class which, as having hydrogen for their base, are called *hydrogen acids.* In the mineral kingdom binary compounds of this element are to be found with certain non-metallic substances (Sulphur, Chlorine, Bromine, Iodine, Selenium, and Fluorine), and with the metals arsenic, antimony, and Tellurium; in the animal and vegetable kingdoms it forms ternary combinations with nitrogen and carbon. In chemical nomenclature they are distinguished by the prefix *hydro.*

From among many the following instances may suffice, viz.

Hydrochloric Acid, comp. of 1 hydrogen and 1 chlorine $= H\ Cl$.

Hydrosulphuric Acid, comp. of 2 hydrogen and 1 sulphur $= \underline{H}\ S$.

Hydrocyanic Acid, comp. of 2 nitrogen, 2 carbon, and 2 hydrogen $= N^2\ C^2\ H^2$ or $\underline{N}\ \underline{C}\ \underline{H}$.

vegetable blues green, and vegetable yellows brown

The mineral alkalies consist chiefly of binary c
oxygen with the metals; the animal and vegeto-a
contrary, are for the most part composed of the fou
of organic nature and contain from $\frac{2}{3}$—$\frac{3}{4}$ of their we
a large proportion of hydrogen, and a little oxygen

A few of the principal alkalies are,

Oxide of Potassium or *Potassa*, comp. of 1
1 oxygen = $\dot{K}$.

Oxide of Sodium or *Soda*, comp. of 1 sodium
= $\dot{Na}$.

Oxide of Calcium or *Lime*, comp. of 1 calci
gen = $\dot{Ca}$.

Oxide of Strontium or *Strontia*, comp. of 1
1 oxygen = $\dot{Sr}$.

§ 69.

The most important and most generally diffused
are the *oxygen acids* and the *oxides*. Both howev
ferent quantities of oxygen with the same radical,
may — agreeably to the law laid down in § 64. —
various proportions with the other element of the
degree of the quantity of oxygen present is sh
change in the appellation.

If two acids are thus formed, that which con
portion of oxygen is distinguished by the termi
the name of the other ends in *ous*, as,

r proportions obtain also in the combinations of the n-metallic substances, the chlorates, sulphates, &c., tensities are marked in a similar manner.

§ 70.

rent combinations of this class may be known by their properties neither of acids nor of alkalies, and espe- r exhibiting no chemical affinity.

neral kingdom belong all alloys and some oxides. re called *Suboxides* and *Superoxides;* adopting this nenclature the following would be the gradation: — e, *Superoxide*, Acid, and the quantities of oxygen in a simple numerical proportion.

of manganese (Base) = $\overset{\cdots}{\underline{\text{Mn}}}$.

oxide of manganese = $\overset{\cdot\cdot}{\text{Mn}}$.

aneseous acid = $\overset{\cdots}{\text{Mn}}$.

s case the following will be the proportion of oxygen: 3 or 3 : 4 : 6.

ide of potassium = $\overset{\cdot}{\underline{\text{K}}}$.

of potassium = $\overset{\cdot}{\text{K}}$

oxide of potassium = $\overset{\cdots}{\text{K}}$.

portion of oxygen being as ½ : 1 : 3 or 1 : 2 : 6.

rent combinations of the animal and vegetable king- eir acids and bases, consist of the four elements e already said enter into the composition of all organic

g these may be reckoned various parts of plants and as the woody fibre of trees, gum, fat, oil, rosin, co- matter, &c., besides alcohol and ether.

§ 71.

pounds of the first order, in addition to the elements y are chemically composed, contain also a portion of t which indeed some of them cannot exist. In this they are known as *hydrated oxides.*

ated sulphuric acid = $\overset{\cdots}{\text{S}} + \overset{\cdot}{\underline{\text{H}}}$.

ated oxide of iron (rust) = $\overset{\cdots}{\text{Fe}} + \overset{\cdot}{\underline{\text{H}}}^3$.

supply of oxygen.

Hence the extinguishing of burning miss them with damp earth, or hides.

§ 78.

Many solids possess the property, upon comin a fluid body, of themselves becoming fluids also, it one homogeneous substance. This condition of its *Solution*, and the fluid which brings about the a *Solvent*.

§ 79.

A distinction must here be remarked betw *mechanical* solutions.

In *Chemical Solutions* a perfect chemical union the liquid is produced, in accordance with the proportions established in §§ 63. and 64. Both of the compound exhibit a change in their proper bined in an entirely new substance formed by t substance, on the completion of the process, ge solid form, that is, it becomes crystallised. Am and most powerful solvents of this class may be *phuric*, *nitric*, and *chloric acids*.

§ 80.

Mechanical Solution is the mere union of a soli such a manner that its aggregate form is char st one of the bodies, the solvent, must be a liquid; in the ter, both the substances are solids, and liquefaction must be ught about by means of heat before any combination will take ce “*corpora non agunt nisi fluida.*” *Bronze*, for instance, is such olution of copper and tin.

§ 82.

The strength of any particular solvent, when employed, varies uch according to the properties of the body to be dissolved. A lution is said to be *saturated* when no more of the solid can be issolved. With respect to the chemical solutions, saturation deends, as has been observed above, on the number of equivalents nd on the established laws of chemical combinations; in aqueous olutions, on the contrary, saturation depends greatly on the temerature of the water. In general, the capacity for dissolving ncreases as the temperature rises, and in chemical solutions, too, the elevation of the temperature materially affects the result; *chloride of sodium* (culinary salt) is equally soluble in water at all temperatures; whilst *oxide of calcium* (lime) is more freely dissolved by cold water than by hot.

§ 83.

The *crystallisation* of any body that has been dissolved consists in its solidifying, and in the separation from it of its solvent. It is effected either by the gradual cooling of a hot solution, in which case with the fall of the temperature there is a corresponding diminution of the dissolving power, and thus the solid crystallises; or else, by the application of heat, the liquid is driven off up to *the point of crystallisation*, when the surface of the fluid will be seen to be overspread with a thin film.

Water is capable of holding several salts in solution at the same time. When the temperature of the water has been so lowered by cooling, or such a quantity has been driven off by evaporation that it can no longer hold in solution the given quantity of any one of the salts, then that particular salt disengages itself, and crystallisation begins, the other salts continuing in solution till from a like cause they successively crystallise. Hence we are able to separate any number of salts from each other.

Application of this in the purification of saltpetre from the common salt mixed with it.

§ 84.

In the chemical decomposition of solutions, the disengaged body may be either solid, liquid, or aëriform.

In the first case it thickens, and often colours the liquid, sinking at length to *the bottom*, whence it is called a Precipitate.

atoms of which the bod
posed (3).

1) As an illustration of the subdivi may adduce a cube of fluor-spar, which gi its primitive form; or a hexagonal cryst which gives a rhomboid.

Haüy, who first discovered the import of the subdivision of crystals, obtained the forms, the *tetraëdron, fig.* 23.; the *parall* the *octoëdron, fig.* 25.; the *hexagonal p*

Fig. 23.

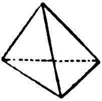


Fig. 24.

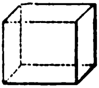
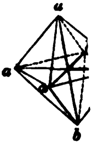


Fig. 25.



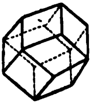


Fig. 27.

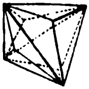


Fig. 28.

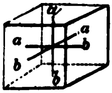


Fig. 29.

sulphur, and bismuth. — Microscopic crystallisation of the above substances.

The crystallisation of tin in the tinning of iron plates becomes visible when acted upon by nitric acid, and produces the well-known ethiop's mineral.

The planes of cleavage are readily distinguished in lead ore, Iceland spar, &c.; also in zinc, antimony, bismuth, &c.

2) A piece of Iceland spar, if broken into its smallest particles, gives perfectly formed rhomboidal crystals.

Haüy regarded the parallelopipedon, the tetraëdron, and the triangular prism as the forms of the ultimate molecules, which suffice for the production of every other form. He supposed crystals to be composed of these molecules arranged in courses one upon the other. The great variety of crystalline forms derived from so small a number of primitive ones he explained, on the supposition that the strata diminish gradually as their distance increases from the primitive nucleus, and that this takes place either at the angles or at the sides only, or in a position intermediate between them. Thus, *ex. gr.*, from the cube, as the primitive form, may be derived by means of combination, the *octoëdron*, *fig.* 31.; the *rhombendodecaëdron*, *fig.* 32.; and the pentagonal-dodecaëdron, *fig.* 33.

Fig. 31.

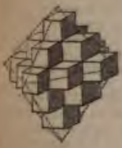


Fig. 32.

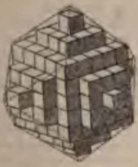
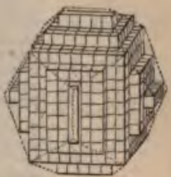
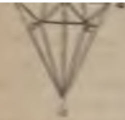


Fig. 33.



It might, perhaps, seem more natural to consider the primitive form in all cases as the basis of the different crystalline bodies; in order, however, to facilitate the description of the various specimens of crystals — particularly in classifying minerals — certain forms are assumed to be *fundamental*. The number and kind of hese fundamental forms are variously stated by different crystal-ographers. Such crystalline forms as may be deduced from one f these fundamental forms are said to constitute a *System of Crys-allisation*.

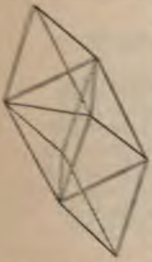
The chief points to be regarded in crystals are the angles and he centres of their edges and sides. The lines joining these oints, and *passing through* the middle of the crystal, are called



toëdron, *fig.* 25., have e
either of which may be r
principal axis. The six
pyramid, *fig.* 54., has four
a b is the principal, and
subordinate axes.

The term *amorphous* is applied to such miner
with in shapeless forms, which forms have perh
duced by some external causes that have inter
body's assuming its own appropriate form; if

§ 88. "But," says Mr. Brande in his 'Chemistry,' vol. i. p
lography we meet with appearances which Haüy's theory b



plains. A slice of fluor spar, for inst
making two successive and parallel
divided into acute rhomboids; but
primitive form of the spar, because,
a tetraëdron from each extremity of
octoëdron is obtained. Thus, as th
fluor may be divided into tetraëdra
becomes a question which of these fo
primitive, especially as neither of th
without leaving vacuities; nor can
arrangement sufficiently stable to fo
permanent crystal.

To obviate this incongruity, Dr.
Trans. 1813) ingeniously proposed to
mitive particles as spheres which, by
have assumed that arrangement whic
near as possible to each other. Wh
similar balls are pressed together in th
form equilateral triangles with each ot
so placed were cemented together, and afterwards broken asu
lines in which they would be disposed to separate would fo

ructure be also destitute of anything of a crystalline nature, the bstance is said to be dense.

Crystalline bodies frequently differ widely in their physical roperties from non-crystallised, especially in the greater hardness f the former. The most remarkable instances are afforded in rbon and aluminum, which, when crystallised, become the ardest of known substances, the diamond and the sapphire.

§ 89.

The various modifications of cohesion, expressed by the terms *hardness*, *softness*, *brittleness*, and *ductility*, applied to solid bodies, may be accounted for as arising from the variations in their internal structure.

Those bodies are said to be *hard* which resist a considerable external force, either by pressure or impact.

Most stones, several metals, and various kinds of wood, possess this quality. Of two bodies that is said to be the harder which causes a disruption of the other; the diamond is esteemed the hardest of all bodies, because all others may be cut by it, but it cannot be cut by any one of them.

Soft is a term applied to all such bodies as may be made to change their form on the application of a trifling force, no disruption of their parts taking place, and the form thus impressed upon them being retained after the force has ceased to be exerted upon them.

Moist clay, tallow, butter, wax, &c. may serve as familiar examples of soft substances.

Those hard bodies whose particles are held in such a state of mutual repulsion, that the separation of one or more of their particles causes the disruption of a large portion of the body, or even its total dissolution are said to be *brittle*. This property may be induced in many bodies, by raising them to a red heat, and then cooling them suddenly.

Brittle bodies may be pulverised with ease by applying some external mechanical force. Glass that has been cooled quickly, and highly tempered steel, possess this quality in a remarkable degree.

First Exp. If the tail or glass thread be broken off a Dutch-tear (*i. e.* a liquid glass-drop cooled by immersion in cold water), the whole body falls into minute fragments. Let a small sharp piece of gun-flint fall into a Bologna flask, and it will break it into a number of pieces.

Glass cooled slowly does not display this brittle nature; but by the more gradual loss of its heat it acquires a greater or less degree of elasticity, as may be seen in fine threads of glass.

nected with the arts, as, *ex. gr.*, iron, copper zinc. Gold, silver, and platinum are mallea ably high degree — gold-leaf, silver-leaf, pl and silver wire; Wollaston's finest platinum

Those bodies which admit of being bent witho which retain the form they have thus been made t to be *ductile* and *pliable*.

All the malleable metals have this prope iron in a remarkable degree; many other sol it too; as, for instance, the roots and twig catgut, &c.

These different modifications of solidity a qualities that invariably admit of strongly demarcation, nor are they unsusceptible o degree in the same body. Heat seems to fluence on them, as the accumulation of th body always diminishes its cohesive attra details on this subject belong to the doctrine

The following little table furnishes, at a gl tive view of the different properties of the ch of solid bodies: —

A Body may be	Pliable	
hard	heavy	
brittle	heavy	
ductile	light	

end, offers to a force acting at the other end in the direction of the body's length, and *tending to tear it asunder.*

2. Their *lateral strength*, or the force with which a beam fastened or supported at one or both ends resists *rupture*, the stress being applied perpendicularly to the beam.

3. Their *resistance to compression*, or the force which a body opposes to a weight applied in the direction of its length, with a tendency either to *crush* the body, or by *deflecting* it to break it.

The weight required to effect the particular kind of rupture is, in every case, the measure of the body's strength.

As it is of considerable importance in many matters connected with art, to know the strength of different substances, experiments have been performed to test this point. The metals, woods, and cords have chiefly been tried, these materials being the most extensively used. The general result of these investigations is, that the strength of the metals exceeds that of the woods, and that among different bodies of both these classes a great inequality subsists.

The capacity of any substance for resisting tension is of importance in determining what force of traction it can withstand, applied in the direction of its length; as in suspension-bridges, anchors, cables, and the like.

In order to estimate the strength of the material under investigation, whether it be wire, rod, or cord of several strands, let its upper extremity be securely fastened, and then attach weights to its lower end, till rupture takes place. That weight which snaps the body is regarded as the measure of its absolute strength.

The following is a list of the metals, according to their strength, beginning with the strongest: —

Steel, wrought-iron, cast-iron, platinum (?), silver, copper brass, gold, tin, bismuth, zinc, antimony, lead.

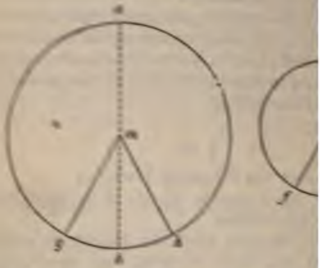
It has further been ascertained, that the tenacity of cast metals is less than that of the same metals when forged and drawn into wire; that alloys frequently affect their strength in no small degree; and that metals at a low temperature are much stronger than when heated. — Necessary application of these principles to the boilers of steam-engines; effect of constant use upon the barrels of fire-arms.

In consequence of its great tenacity, iron is the most important metal, in a technical point of view. According to Tredgold's and Duleau's experiments, a piece of the best bar-iron 1 square inch across the end would bear a weight of about 77,373 lb., while a similar piece of cast-iron would be torn asunder by a weight of from 16,243 to 19,464 lbs. It is worthy of remark, that thin iron wires, arranged parallel to each other, and presenting a surface at their ex-point, B, in the same time that they would

the diameter A B.

If now the diameter, A B, of the circle
body would occupy one second in falling
A B = $4 \cdot 16\frac{1}{12}$ feet, then the body would re
if A B = $9 \cdot 16\frac{1}{12}$ feet, three seconds (§
(*fig.* 44.) be four times as great as *cd*, a b

Fig. 44.



twice as long a time to fall through *gb* as
fd. If *ab* be nine times as great as *cd*, or
great as *od*, the time in falling through *gb*
longer than in falling through *fd*, and so
the higher mathematics, it has been demo
times in which bodies move through the

follows, that if we wish to make the duration of an oscillation 2, 3, 4, 5, &c. times greater, we must lengthen the pendulum 4, 9, 16, 25, &c. times, *i. e.* the lengths of the pendulums must be as the squares of their times.

§ 102.

A *Seconds pendulum* is one whose vibration occupies one second.

As the motion of a pendulum, like the fall of bodies *in vacuo*, or their descent on an inclined plane, is a consequence of the earth's attraction, the length of a seconds pendulum must depend on the intensity of this force (*a*). Where gravitation is equally powerful, all pendulums vibrating seconds must be of equal lengths; and where this force does not vary, the length must continue constant. If the attraction increases, the pendulum will beat more quickly; if it diminishes, its vibrations will be slower. Observation has shown, that a pendulum beating seconds at the equator oscillates more rapidly as it approaches the poles (*b*). Hence it follows that the force of gravity must increase towards the poles, and that the cause of this increment is the flattened figure of our earth, *i. e.* that the axis of the earth is shorter than its equatorial diameter. Under the equator, the length of a pendulum beating seconds is 439·2066 Paris lines; and under the poles 441·5928 Paris lines; the entire difference between these two extremes being only 2·3862 Paris lines, or little more than $\frac{1}{5}$ of an English inch; in the latitude of London the length of such a pendulum is 39$\frac{1}{8}$, or, more accurately, 39·13929 inches, at the temperature of 62° Fahr.

a. If the time in which a pendulum described a small arc were exactly equal to that in which it would move along its chord, then the length of a seconds pendulum would be exactly the fourth part of the height fallen in the first second of time. But, according to the observation made in the preceding §, 2, it has been shown mathematically that the time is something less. The calculation may be made by formula A in that article: thus,

$$t = \pi\frac{\sqrt{l}}{2g}, \therefore l = \frac{t^2 \cdot 2g}{\pi^2}, \text{ if } t = 1 \text{ sec.}$$

$$\text{then } l = \frac{2g}{\pi^2} = \frac{g}{4{\cdot}9348} = 0{\cdot}2026\, g.$$

b. Richer (1672) discovered that a pendulum beating seconds which he carried from Paris to Cayenne, moved in this latter place rather more slowly. Newton thence deduced, by *his second law of gravitation*, the flattened form

impact of *hard inelastic* bodies and that of
with the penetration of such as are soft, beca
coming divided, their parts can no longer
collision.

Hardness and *Elasticity* are essential
(§ 6. 89.), consequently there exists no su
solutely hard or a perfectly elastic solid.
are about to develope must, accordingly, b
difications varying in degree; in theory, b
to be absolutely hard or absolutely elastic,
or the other of these qualities predominate

§ 105.

In perfectly hard non-elastic bodies, the mo
divided proportionately to the masses. If two
in one direction, after impact their joint momen
to the sum of their single moments. If they
directions, it will equal the difference of thei
common velocity of the two bodies, after im
dividing the common momentum by the sum
weights.

Let M and m represent the masses, and
cities of two bodies; then the motion of th
after impact, if they move in the same dire
(Comp. obs. § 28.)

Let their common velocity after imp
momentum of the united masses $= x$ (
$(M + m) = MV + mv$; consequently

and that of the second body,

$$4.,\ mx = \frac{m(MV - mv)}{M + m}$$

whence the momentum lost by the first body is

$$MV - \frac{M(MV - mv)}{M + m} =$$

$$5.,\ \frac{Mm(V + v)}{M + m}$$

and by the second body

$$mv + \frac{(m\,MV + mv)}{M + m} =$$

$$6.,\ \frac{Mm(V + v)}{M + m}$$

or the moving force of both bodies is equally diminished.

If one body, *ex. gr.*, m, be at rest, then $mv = 0$, and in this case

$$7.,\ x = \frac{MV}{M + m}$$

If $M = m$, then

$$8.,\ x = \frac{V \pm v}{2}$$

When $V = v$, in which case only equation 2. admits of application,

$$9.,\ x = \frac{M - m}{M + m} \cdot V$$

Lastly, if $MV = mv$, and both bodies move in the same direction,

$$10.,\ x = \frac{2\,MV}{M + m}$$

and if they move in opposite directions,

$$11.,\ x = \frac{MV - mv}{M + m} = \frac{0}{M + m} = 0$$

In order to test experimentally the accuracy of these laws, we must set perfectly hard and non-elastic bodies in a state of central motion, so as to produce impact, by which means we may estimate the velocity of the bodies with tolerable accuracy. The following arrangement will be found available from its simplicity: suspend two balls near to each other in the manner of a pendulum, taking care that they shall describe their oscillation in the same arc; when they

of the ivory balls in the impa
ivory being the substance tha
perfectly elasticity.

If 100 elastic balls were susp
they just touched, their centres
and each successive ball containi
of the preceding, then the velo
$=(\frac{4}{3})^{99}$ or 233850000000 times t
city would amount to more th
second, supposing the first to m
foot; in other words, the last ba
nearly equal to 5 times the earth
one second of time. Such an ex
appear easy to accomplish on its
the first ball have a diameter o
would have a diameter 20 times
earth, and its solid content would
that of the earth.

§ 110.

If an elastic body in motion strike ar
rest, the former will recoil with a vel
which it advanced. If the impact wer
in the same direction; but if it were i
under the same angle, but in the o
expressed thus: the *angle of incidenc*
Let *a b* (*fig.* 48.) be the direction in
the plane, *b a′* will

Resolving the original force *ab* by means of the parallelogram of forces (§ 23. and 24.) into the components *ac* and *ad*, we may establish the accuracy of the above conclusion. When the body *a* has arrived at *b*, the force *ac*, in consequence of the body's elasticity, causes it to return in the direction $bd = ac$, whilst the other component $bc = ad$ produces a tendency to move towards bc'. It is, therefore, simultaneously driven forward from the point *b* by the two forces *bd* and bc'; it will of necessity describe the diagonal ba' of the parallelogram $bda'c'$. Again, as $bda'c' = bdac$, $ba' = ba$, and $\angle \alpha' = \angle \alpha$ and $\angle \beta' = \angle \beta$.

V. EQUILIBRIUM OF SOLID BODIES, AND OF THE MECHANICAL POWERS.

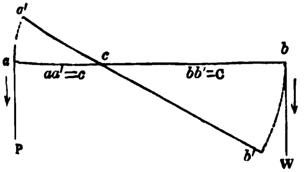
§ 111.

If two or more forces act in opposite directions on a solid body which is fixed, but capable of being moved about a certain point of its mass, such body will either continue in a state of rest, or it will be set in motion.

If the moments of the forces that tend to move the body in opposite directions be equal, it will continue at rest: this condition is called the *Equilibrium* or *Statical Momentum of the Forces.*

If, on the contrary, the moments of the forces in one direction exceed those in the other, the body will be set in motion in the direction of the greater momentum.

Fig. 49.



Let *ab* (*fig.* 49.) be the solid body capable of being turned about the point *c*. Suppose the mass *m* to act on *b*, and M on *a*, then if the line turns about *c* the momentum at *b* (§ 27.) is $m.bb' = mc$, and at $a = M.aa' = MC$. If these products are equal, but the directions in which they tend to excite motion are opposite, their effects will be neutralised, and the line will remain at rest; if they are unequal, the line will move in the direction of the greater momentum.

Now, since the moments are the products of the forces or masses, M, *m*, into their velocities, C, *c*, in the condition of equilibrium we obtain,

$$MC = mc$$
$$\text{or } M : m :: c : C$$

cessary to increase the force acting

§ 112.

On this general law of the action of motive pow bodies depend those various contrivances known by name of *machines.*

Machines in general are employed, either

1. by means of a small force to hold *in equilibrio,* o motion a great weight, or

2. by means of a considerable force to impart a grea a small body.

There are six *simple machines,* viz. the *Lever,* the *Wheel and Axle,* the *Inclined Plane,* the *Wedge,* and the the different *compound* machines, which have been or constructed, consist only of various combinations of th ple ones, generally known as the *mechanical powers.*

a. THE LEVER.

§ 113.

A *physical* or *compound lever* is any inflexible rod whatever, supported on one point, and acted on points, by two forces tending to move it in opposi about the point of support. If, instead of such a bod will conceive of an inflexible imponderable line, he *mathematical* or *simple lever.*

§ 114.

Fig. 50.

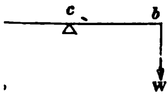


Fig. 51.

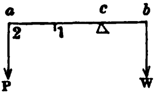
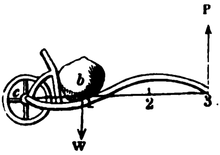
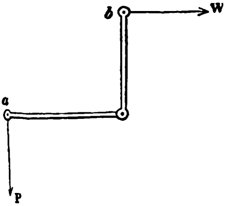


Fig. 52.



may have unequal arms, as in *fig.* 51., where the fulcrum is earer to one of the forces than to the other.

Fig. 53.



The arms of a lever may be either right or curved lines, or they may even form an angle, in which last case the fulcrum will be at the vertex. *Figs.* 50. and 51. are instances of *rectilinear* levers, *fig.* 52. of a *curvilinear*, and *fig.* 53. of an *angular* lever.

§ 116.

The following law holds true with levers of every class: —

1. *Every lever is in a state of equilibrium when the power and weight are to each other inversely as their distances from the fulcrum* (a): or,

2. *Equilibrium obtains in a lever when the moments of the forces acting on the lever are equal.* (§ 111.)

Thus, according to *figs.* 50, 51, 52, 53., if

$$P : W :: cb : ac, \text{ or}$$
$$P . ac = W . cb.$$

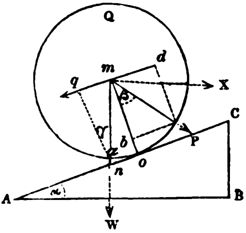
a. The distance of a force from the fulcrum is the perpendicular that may be drawn from that point to the line of direction of the force. If the forces act perpendicularly on the arms of the lever, the arms will themselves be the distances; if they act obliquely, a perpendicular drawn from the fulcrum to the line of direction of the force gives the distance. Pa' is the direction of the force P (*fig.* 54.), and the perpendicular, ca', its distance; Wb' is the direction of the weight W, and cb' its perpendicular or distance.

If the angles α and β are known, which the directions of the forces make with the arms of the lever, then by trigonometry it may be found that or P : W :: *cb* :

As in this case Δ *cba* is not similar tc between the arms of the lever can no lc sides of the plane.

All the three sides may be genera

Fig. 71.



Represent the weight W of the bc line *mn*, which being considered as a into the components *mo*, *mq* (§ 24.), pressure on the plane, and *mq* is the force with which Q tends to move in $mq = mn . \sin . \gamma$, and from the similarit CAB, $\gamma = \alpha$; whence the relative w whilst the pressure

$$\text{whence } P = W. \frac{\sin. \alpha}{\sin. \beta}$$

If P be parallel to A C, as in the direction md, then $\beta = 90°$, and $\sin. \beta = 1$, in which case;

$$P = W . \sin. \alpha = W . \frac{\text{perp.}}{\text{hyp.}} \quad \text{(Case I.)}$$

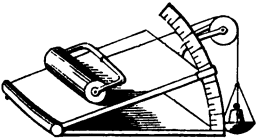
If P be parallel to the base A B, as mx, $\beta = 90 - \alpha$, so $\sin. \beta = \cos. \alpha$, whence

$$P = W . \frac{\sin. \alpha}{\cos. \alpha} = W . \tan. \alpha = W . \frac{\text{perp.}}{\text{base}} \quad \text{(Case II.)}$$

From what has been shown above it follows as a general rule, that the saving of power effected is greater the less the perpendicular height of the plane is as compared with its hypothenuse; that the maximum saving is when the power acts parallel with the inclined side; and that the power must be increased in proportion as the direction in which it is exerted approaches a perpendicular to the inclined plane.

Exp. The laws of equilibrium in the inclined plane may be experimentally verified by laying a ball or cylinder, of known weight, upon a smooth board inclined at different angles; a cord passes from the cylinder over a pulley in such a manner that it may act parallel to the inclined side, parallel to the base, or at any angle that may be required; the other force is represented by a weight placed in a scale attached to the other end of the cord. See *fig.* 72.

Fig. 72.

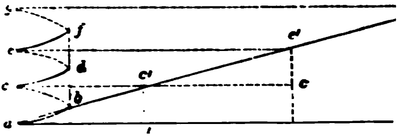


The chief use of the inclined plane, considered as a mechanical power, is in the construction of convenient ways for the transmission of heavy loads, which are to be raised to some particular height by but a small expenditure of power.

The ladders used by brewers to lower casks into a cellar; the inclined plane down which a ship is launched. Application in fortification, in the inclines by which you ascend a rampart. In what direction is a force applied most advantageously upon an inclined plane? When must the horses exert the greatest force in drawing a load up-hill?

the right angle

Fig. 76.



The hypothenuse will describe the screw-line abou of the cylinder. Every part of this line which go the periphery of the cylinder, as *abc*, *cde*, *efg*, is c the *worm* or *thread*, and each such part requires an of the triangle, $aa'=cc'=ee'$. The distance of o the next, $ac=ce=eg$, and which coincides with the corresponding portions of the triangle, $a'c'=c'e'$ the *breadth* of the screw.

If the screw-line consists of one continuous cylinder forms a *male screw*; if, on the contrary, the cylinder contains a winding cavity, it is called *screw*. The combination of both these parts cons chanical power known as the screw.

§ 130.

The working of the screw may be deduced fr inclined plane, the weight resting on the inclin

W being the weight or resistance to be overcome, h the height or distance between the threads, and r the radius of the screw.

The space described by the power is to that described by the resistance as the circumference of the screw to the distance between two of the threads.

Power is therefore economised the nearer the threads of the screw approach each other, *i. e.* as the distance between them is diminished as compared with the perimeter of the cylinder. In applying this mechanical power, either the *screw* or the *nut* by its progressive motion may be made to exert the power or overcome the resistance, according as the other revolves about its axis.

The purposes to which the screw is applied are very various; it serves,

1. *To compress bodies closely together;* as, for instance, in the different kinds of presses, machines for stamping coins, vices, &c.

2. *To raise weights;* as when it is used in adjusting guns; and,

3. *To produce uniform and delicate movements*, as in the case of divider compasses, and the micrometer screws of different instruments.

§ 131.

The screw is occasionally used to set in motion sun-and-planet wheels, the worm of the screw working into the teeth of that wheel which drives the gear, and by its revolution compelling the wheel to turn about its axis. Such a combination is termed an *endless screw.*

This machine is employed partly to raise loads—as the adjustment of cannon—but principally to show delicate and uniform circular movements in various instruments; *ex. gr.*, Ramsden's Dividing Machine.

§ 132.

With the screw we conclude the catalogue of the mechanical powers. On comparing the remarks made on each of these simple machines, it will be found that all the laws which regulate equilibrium in each, either depend immediately on what was established with regard to the lever (§ 116.), or may be deduced from the principal laws of motive powers (§ 111. Obs.); we are consequently constrained to regard *the lever* as the *fundamental machine.* Again, as all compound machines are merely combinations of the simple ones, it follows that *the lever furnishes the fundamental law for the entire theory of machinery.*

The simple machines do not meet the requirements of actual

even their
this that when the wheels
compressed by them, this
of the wheel being tapered
it is therefore important tha
breadth that they may not
According to Babbage, on
amounts to $\frac{1}{71}$st part of the
nearly double, or $\frac{1}{33}$th; when
spread it is $4\frac{1}{2}$ times as much
set of experiments, an ordin
weighing together 1000 lb.,
traction of 250 lb. ($\frac{1}{4}$); on a fre
on a common by-road, 106 lb.
meadow ground, 40 lb. ($\frac{1}{25}$);
25 lb. ($\frac{1}{40}$). According to Be
traction required on different
load Q will be for hard maca
such a road in a muddy sta
meadow ground, 0·04 Q.; on
mon, not macadamised, roads
covered with stones, 0·143.; an

These experiments, and the
mote industry by transporting it
another with the greatest possib
were to commerce, led to the
roads, the full effects of which it
ration to develope. The princi
greatest practicable

regard to the different cases of friction, the most important point will be seen to be,

1. That friction increases,
    - *a.* As the pressure or weight is increased.
    - *b.* As the areas of the surfaces in contact are increased.
    - *c.* As the roughness of the surfaces is increased.
2. That friction may be diminished,
    - *a.* By lessening the weight of the body in motion.
    - *b.* By mechanically reducing the asperities of the sliding surfaces.
    - *c.* By lessening the amount of surface of homogeneous bodies in contact with each other.
    - *d.* By converting a sliding motion into a rolling one.
    - *e.* By applying some suitable unguent.

In order practically to determine the amount of friction in any particular machine, hang weights to it until the machine just begins to move. In this way the amount of friction is obtained when motion commences, and (by 3) it has been shown that this always exceeds the friction which obtains after all parts of the machine have for some time been in play.

§ 136.

Whilst, as has been shown above, friction is one of those natural evils which invariably consume some portion of the power ex-ended in producing any motion whatever, and by consequence in many points of view it may be regarded as highly prejudicial, yet f viewed in another relation we shall find that it is of incalculable dvantage. Were it not for friction, nothing could be nailed, rewed, or tied together, or even securely held in the human and. All solid bodies, including ourselves and all other ani-ated beings, would occupy a stable position only upon a per-tly level plane, and all matter would present a smooth surface, ke water, whilst the entire mass would endeavour to descend to e lowest possible point and there settle.—Instance the unsteady it of a man walking on smooth ice. The bricks ranged one on the other forming a wall that defies the violence of the rm, nay, the solid rock itself, which the hurricane fails to shake, indebted to friction for their firm position; deprive their terials of this property, and the slightest push would level m with the ground.—The revolution of a cart-wheel is owing he rolling friction excited by the inequalities of the road; in cending a hill it is frequently necessary to lock the wheel in er to increase the friction.

have a velocity of 3 feet, it must then
the fluid 3 feet in length with a velocit
ance, found as before, amounts to 3 ×
proportional to the square of the veloci
generally; put M = the mass of the
1 second of time, and v the velocity
effected, the resistance will be M v.
comes greater the greater the velocity.
of the plane moving against the fluid,
driven on by such plane in 1 second wil
Substituting this value of M as the mea
$q v . v = q v^2$.

Bodies of similar figure and of the
come the resistance of the medium thro
the more easily, or, in other words, wi
ture of motive power, the greater thei
of the same material will, accordingly,
resistance from the air the more mas
Now, suppose the diameter of an iron
of another 3-inches, their masses will be
if they have equal velocities their mo
the same ratio. By 2. in this §, the res
in which the motion occurs is proporti
of the plane that moves against it;
varies as the squares of their respectiv
present example the 1-inch ball meets
whilst the 3 inch ball sustains one of
plain that the ratio of 1 : 9 is less tha

than that of the solid one, the loss of motive power sustained by the former will exceed that sustained by the latter. Consequently, in artillery, one object to be attained is to make the missiles of the densest possible substance.—The pressure of bullets in a mould, and the forging of cannon-balls.

The laws laid down under the three preceding heads coincide, however, with experience only under certain mean velocities; with very high velocities, as with extremely low ones, the resistance decreases; in the former case, chiefly because the compressed fluid resumes the place made void by the moving body with a velocity less than that of such body, so that a vacant space exists behind any mass that is projected with extreme velocity. This is the case with the motion of any body through the atmosphere with a velocity exceeding 800 ft.

§ 139.

The resisting forces that have been explained in the foregoing
agraphs cause the actual motions of bodies to deviate mate-
ly from the laws established in the earlier part of this volume,
in accordance with which these very forces themselves have
n illustrated.

Thus it has been said, that every body on which a momentary
e acts will move in a right line, and persevere in such motion;
ually, however, this does not happen. The impediments with
ch we have now become acquainted oppose themselves to this
ion, lessen the velocity, and, after retarding the body for some
e, bring it to a state of rest.

he descent of bodies falling freely is not a uniformly accele-
d motion, but is one constantly approximating to it. When
resistance of the air equals the force of the motion produced
terrestrial gravitation, this is fully seen; hence it follows, that
bodies do not fall from the same height to the earth in equal
es: the denser bodies more easily overcome the resistance
red, because, with the same volume as others of less density,
with the same amount of resistance from the medium, they
e a greater motive power.

A coin, for example, falls more quickly to the ground than a scrap of paper; but in an exhausted receiver (as will be shown presently), where the resistance of the air is nearly destroyed, both bodies descend with equal rapidity.

The motion of a body on an inclined plane must evidently
iate still more from accelerated motion, since friction is added
whatever impediment may arise from the medium in which the
ly is placed.

A pendulum or a ball on a concave circular superficies (§ 37.),
ich bodies, *but for these* modifying causes, would be a kind of

the water, on a
the glass.

§ 153.

Bodies immersed in a fluid are pressed with a force increasing as the depth.

Exp. Tie a small bladder to a gla a small portion of the tube, with plunge the apparatus into a vessel will be observed to ascend in the tube, to the depth of the bladder below the

This pressure is equal to the weight of a c for its base the surface of the body, and for i the body's centre from the surface of the fluid

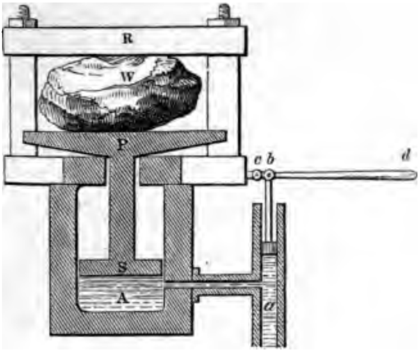
Empty bottles, if closely corked a able depth in the sea, are sometim means, and sometimes have the cork Scoresby relates that the wood of a drawn by a whale 1000 feet below the consequence of the pressure, became that it would not float again, even aft If a cubic foot of sea-water, Paris mea required the pressure on a surface of 1 1000 P. feet.

§ 154.

If a pressure be exerted by means of any
ever, against the

placed the substance to be compressed, W. In the narrow tube *a* is a piston, *s*, worked by a lever, *cbd*, its short arm *cb* driving the piston while the power is applied at *d* The

Fig. 81.



pressure exerted by the small piston *s* on the water at *a* is transmitted with equal force throughout the entire mass of the fluid, whilst the surface at A presses up the piston S with a force proportioned to its area. For instance: if the cylinder *a* of the force-pump has a diameter of ½ an inch, while the great cylinder has a diameter of 200 inches, then the pressure of the water in the latter on the piston S 2.200=400 times that on *s*. Next suppose the arms of the lever to be to each other as 1 : 50, and that at *d*, the extremity of the longer arm, a man works with a force of 50 lb., the piston *s* will consequently descend on the water with a force of 2500 lb., and the head P will rise with a force of 400.2500=1,000,000 lb.; if, according to Nicholson's calculation, we deduct ¼th for loss of power caused by the different impediments to motion, by means of this machine one man would still be able to exert a force of ¾ of a million lb. This press is used in pressing paper, cloth, hay, gunpowder, &c.; also in uprooting trees, testing the strength of ropes, &c.

Exp. In a glass full of water, immerse the end of a Dutch-tear. As soon as the glass thread of the tear which projects above the level of the water is broken off the tail recoils and the tumbler is broken. This proves how instantaneously the concussion is transmitted through all the particles of the water.

equilibrium, only when the [illegible]
by all those on the surface of its mass bei
from the centre of the earth. Since gravi
on all the particles of a fluid that are at e
earth's centre, the motive forces thus gen
other, and the surface is of necessity *hori*
surface of the terrestrial spheroid. Henc
ing law in hydrostatics:—

The surface of every fluid in a state of
variably horizontal.

In accordance with this first law of
fluids obey, they can accumulate or for
spaces — cavities or vessels — as by the
counteract the tendency of the fluids t
laterally.

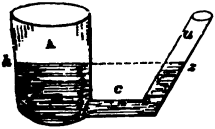
The convex figure of the sea; art
of adhesion to the sides of the vesse

If there be several fluids that do no
will arrange themselves, even if they b
other, as their specific gravities diminis
densest fluid will be at the bottom of t
the top, the strata when in a state
horizontal.

Exp. In a tall narrow glass,
some quicksilver, water, oil, alcol
together these ingredients, and o
the appearance spoken of above.

First Exp. Let A and *a*, *fig.* 82., be two glass vessels communicating by the tube *c*. Pour water into one of them, and it will stand at an equal height in both, the surfaces lying in the horizontal line *h z*. Incline the apparatus, the position of the fluid will be changed, and equilibrium will not again be obtained till the surfaces once more form one horizontal plane.

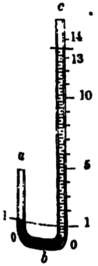
Fig. 82.



On this property depend several applications to the purposes of the arts of life. The level at which a fluid stands in opaque vessels, as boilers of steam engines, gasometers, stills, vats, and the like, is ascertained by means of a glass tube communicating with the larger vessel, and called a *guage*.—The subterraneous water obtained by digging for springs; the water-conduits in towns; the flooding of water in cellars at high-water mark.—The effect of adhesion is perceptible on the unequal tubes when one of them is of very fine bore.

When different fluids are in communicating vessels, their surfaces will be horizontal, but they will stand at unequal heights. — *The levels of the different fluids will be inversely as their densities or specific gravities,* because the forces by which they are pressed down are proportional to these densities.

Fig. 83.

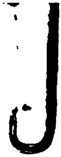


Second Exp. Into one end *a* of a glass tube (*fig.* 83.) pour some quicksilver, and at the opposite end *c* pour water. Equilibrium will obtain when the column *c* is about 13½ times higher than the column of mercury *a*.

§ 157.

If two vessels communicate with each other, and the height at which a fluid stands in one of them exceeds the height of the second vessel, then the fluid cannot stand at a level in these two vessels, but will overflow the shorter one until there remains in the taller vessel only so much of the fluid that its height shall be equal to the height of the shorter.

To this fact we trust in conveying water by means of conduits for the supply of cities; to this hydrostatic pressure, also, are to be attributed the springs and subterranean waters met with *in mining* operations.



pr
me
tu

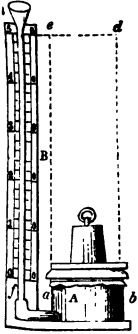
If the shorter of two vessels
be closed at top, and [illegible] be
in the lower vessel it will not
ing. In consequence of the law
the fluid has a tendency to rise
the larger vessel, and this
ward pressure against the lid or
to the weight of a column of the
the superficial content of the lid,
of the levels of the fluid in the

This pressure would be
lid a column of the fluid,

This pressure increases as the
vessel and the difference of the
of the base of the larger vessel.
a small quantity of fluid, to exert
principle act *Wolf's Anatomical*
and, in some degree, *Brahmah's*

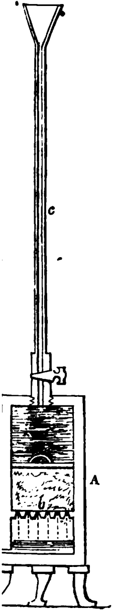
t is raised will depend on that of the column *hf*. This force may be estimated by means of weights laid on the plate. — As 1 cubic inch of water weighs about $\frac{1}{2}$ an ounce, it follows that there will be a pressure of 1 lb. on a surface of 32 square inches if the column of water be 1 inch high. Suppose a section of the cylinder A = 32 inches, every inch of water in the column *hf* above the level *a b* presses with a force of 1 lb. on the bladder with which A is covered; thus, if *ac* were 50 in., and the tube were filled up to the level *c*, the fluid would exert a pressure of 50 lb., which is equal to the weight of a column of water *abdc* standing on A and reaching to the level *cd*. The experiments that can be performed by means of this apparatus will prove the accuracy of some of the laws given above.

Fig. 85.



2. *Real's Water-press* consists of a strong and wide metallic cylinder of but low dimensions, A, *fig.* 86., into the top of which a long funnel-shaped tube *c* is screwed. The cylinder is divided into three compartments by means of two sieve-like plates *a* and *b*, the upper being moveable. Between the two plates is placed the body to be pressed. The compartment above *b* contains the fluid, water, spirit of wine, &c. that is to form the solution. If water is poured into the tube *c*, by the law before referred to the pressure on the fluid in the upper division of the receiver will be increased in the same proportion as the column of the fluid in *c* is increased; the fluid above *b* will then be driven through the body that lies between the plates. Now if the narrow tube be 50 Paris feet long and 1 inch wide, whilst the vessel is 1 foot in surface, the water in the tube, whose weight is 2 Paris lb., will exert a force in the extract receiver of 50·70 = 3500 *Paris* lb.

Fig. 86.



the above formula for v, and assum

$$v = 0{\cdot}621 \cdot 8\sqrt{gh} = 1{\cdot}$$

For example, if the altitude of th were 1·5 feet, then the velocity woul

$$v = 0{\cdot}621 \cdot 8\sqrt{16 \cdot 16} = 0{\cdot}621 \cdot$$

§ 161.

If the vessel is not filled up as the must necessarily descend gradually, an the same rate. Hence, the velocity dim form retarded motion.

For instance, let the level at w inches above the aperture: obser second to 9 inches, i.e. to fall thro in the second equal portion of tim and arrive at the 9 in.; in the t fall 5 in., and arrive at 4 in.; th and arrive at 1 in. from the bas next equal time.

If the fluid is not maintained require twice the time for a vess have sufficed for the same mass altitude remained unchanged.

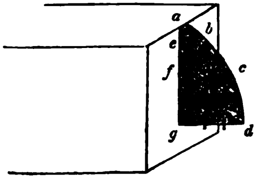
§ 162.

16 ft., it is required to find how many cubic feet of water will be discharged in a second.

$$M = 0{\cdot}621 \,.\, 2 \,.\, \tfrac{2}{3} \sqrt{16{\cdot}16} = 3{\cdot}311 \text{ ft.}$$

Let *ag*, *fig.* 88., be an aperture in the side of a vessel, extending from the surface to a certain depth, or even to the base, in a perpendicular direction, it is clear that the water must issue thence with unequal velocities. According to § 160. the velocity increases with the depth, in the ratio of the square roots of the columns above the aperture. Put the velocity *eb* at *e*, v, and its altitude $ae = h$, the velocity *fc* at *f*, v', its altitude h', the velocity *gd* at *g*, v'', and its altitude h'', then it follows

Fig. 88.



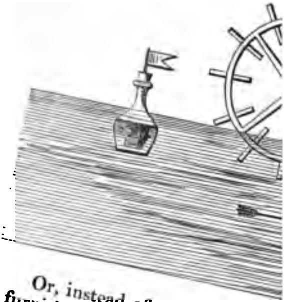
$$v : v' : v'' :: \sqrt{h} : \sqrt{h'} : \sqrt{h''}$$
$$v^2 : (v')^2 : (v'')^2 :: h : h' : h''$$

The ratio thus obtained between the abscissæ h, h', h'', and their ordinates v, v', v'', constitutes the parabola (§ 41.), whence it appears that the water flows out in the figure *agdcba*, which is the section of a parabola, whose content is $\tfrac{2}{3}h\sqrt{h}$, h being the depth of the lowest point of the opening below the surface. Multiply this surface into the width of the opening, and the product will be the quantity of water that issues in 1 second.

Experience, however, invariably shows that a less quantity of water flows from an aperture than calculation by the above theorem would lead us to expect. The difference between the results may in part be accounted for by the mutual adhesion of the particles of water, and also that which they show towards the sides of the vessel; partly also by the theoretical laws of the friction of the fluid against the sides of the orifice; by the resistance of the atmosphere; but most of all by the contraction which takes place in the stream shortly after it issues from the aperture: to this the name of *vena contracta* has been given. This diminution in the circumference of the stream admits of the following explanation; not only, as was at first assumed, does the water perpendicularly above the orifice issue thence, but that which is round about it presses obliquely in all directions towards the aperture, endeavouring to escape from the vessel.

The water in flowing out attains its smallest section at a distance *equal to about half* the diameter of the opening, at ig. 89.

F

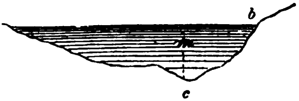


Or, instead of this contrivanc
furnished with float-boards (*fig.*
part of the stream whose velocit
the wheel must be immersed to s
surface of the boards may be per
stream. In this simple apparatus
assumed to be 0, so the circumferer
revolve nearly with the
its amount is

erpoise to the force with which the water is impelled. a column whose altitude is *h* indicates a velocity / $\overline{g\,.\,h}$, the velocity of the stream may hence be deduced y desired depth.

r means of the stream measurer it has been discovered the velocities vary at different points in the same trans- section of a stream. The velocity is found to be greatest ıe middle, where the water is deepest, somewhere in *m* w the surface, *fig.* 92.; thence it decreases with the depth towards the sides, so that it is least at *a* and *b*. In order to learn what quantity of water will flow through such a sec- ı in one second, we must first find the mean velocity by aid of a stream measurer, and then multiply it by the erficial content of the section.

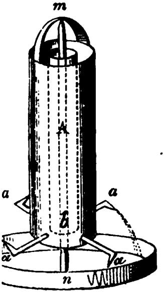
Fig. 92.



§ 165.

r fluid, as water, issues from an aperture in the side of a he pressure on that side is diminished, being consumed in ion of the water. A pressure is, however, generated in a al direction against those parts of the sides that are oppo- the hole by which the water has egress. If the vessel the fluid issues is capable of being moved in the direction ressure, and the force of the stream be sufficient to over- e inertia, a rotatory motion will be imparted to the vessel posite direction to that in which the water flows. *Segner's* ls an application of the power thus obtained.

Fig. 93.



Exp. *Segner's Machine* consists of a hollow cylinder, A, *fig.* 93., which turns about a vertical axis, *m n*, and is kept full of water. At its base are several pipes for the egress of the water, whose mouths *a* are all in one direction, tangential to the circumference of the cylinder. The pressure against the sides of the tubes produces a motion of the vessel in an opposite direction *b*. The motion ceases if the water flow in an opposite direction from an equal number of tubes.

depth.

§ 17

A body floating on a fluid is not
ble position in which it may be p
made between the different position
unstable. In a position of stable f
by the exertion of small forces, but i
position; this is not the case whe
small impulses induce a change of
duces stable equilibrium.

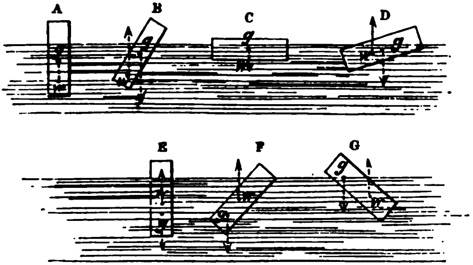
This difference depends mainly on
centre of gravity with regard to that
displaces. The former of these p
same place in the solid, whereas the l
that occur in the position of the p
these points are in the same line of di
of equilibrium or repose. If the cent
below that of the fluid, then the body
if this arrangement be inverted it is
is so placed on the fluid that its ce
greatest surface. Hence it is seen tha
surface is parallel to the water when t
over if this surface be made perpendic

The floating of a plank, a piece
jects, may serve to illustrate the al

A floating body is maintained
parallel to each other, and

so little, as B, both the forces tend towards the position shown in C, when stable equilibrium is gained, as the body floats on

Fig. 100.



its largest surface. If through the oscillations occasioned by its motion it assume the position D, it will again by the operation of the two forces resume its equilibrium of stability C. Lastly, E represents a body whose centre of gravity lies below that of the column of the fluid; E is *in equilibrio.* However, it may be moved from this position; should even the solid's centre of gravity be raised above the level of the fluid, as G, the operation of the two forces would restore it to that of stable equilibrium, E.

In ship-building it is of importance so to place the centre of gravity that the vessel may not be upset, even by violent concussions, but that it may invariably return to its original position of stable equilibrium. — Use of the keel in effecting this. — The due proportion and arrangement of the ballast, though important on other accounts, is especially so as furthering this object.

There are some bodies which will swim in more positions than one; nay, some that will swim in any position whatever. To the former class belong the cube and the cylinder, when the centres of gravity of the solid and fluid the body displaces coincide. A cube will float in a position of stable equilibrium if any one of its sides is perfectly horizontal, and a cylinder if it be placed lengthwise on the fluid. If the centre of the solid's gravity in these bodies be not also their middle point, *i. e.* if they be not of uniform density, then the centre of gravity will continually descend to the lowest place, when they will be in a state of stable equilibrium. Hence it is clear why in the construction of rafts it is advantageous to unite the *timbers as they float.* Lastly, a globe is a body, sup-

silver. The ball will roll and oscillate till i
vity has descended to its lowest position. A
to a state of rest, mark that point of the sph
is highest above the level of the fluid; the c
will lie in the diameter drawn perpendicularl
from this highest point.

V. ON DETERMINING THE SPECIFIC GRAVIT

§ 173.

It has been already (§ 31.) observed that by t
Gravity is meant the proportion subsisting betwe
weights of different bodies having equal volum
weight of distilled water being taken as unity.
the specific gravity of any substance whatever, we
only its absolute weight, but also that of an equa
The most simple and ready mode of effecting this
body in water. It will always be found to disp
water equal to its own, whence the weight lost by t
is equal to that of the fluid displaced. *The s*
density of a body is, consequently, equal to the quo
dividing the body's absolute weight by the weight it l

Thus, expressing it in general terms, let W
weight of a body, and w the weight lost in w
gravity of that substance will be

$$s = \frac{W}{w}$$

perfectly clean, and at some particular temperature. It is usual to take either that at which the density of water is at its maximum, viz. 40° (Stampfer says $+3\frac{3}{4}$° C., or 3° R., which would answer exactly to $38\frac{3}{4}$° F.), or else a mean of 60°.

§ 174.

The following is the method for determining the specific gravity of a solid immersed in water. Its absolute weight is first obtained, it is then weighed in water, and the excess of the former above the latter will be the weight lost on immersion, and, as was said in the preceding §, the quotient obtained by dividing the absolute weight by the weight lost will be the specific gravity sought.

A piece of platinum weighing 52·15 gr. $= W$
lost on immersion - 2·50 gr. $= w$

whence the specific gravity of the platinum,

$$s = \frac{W}{w} = \frac{52{\cdot}15}{2{\cdot}50} = 20{\cdot}8.$$

§ 175.

If the body under examination be specifically lighter than water, in order to immerse it, it must be connected with some substance of greater specific gravity than water, the absolute weight and also the weight lost upon immersion by the second substance being previously known. From the weight lost by the combined bodies deduct that of the heavier, and the remainder will be the weight of the volume of fluid displaced by the lighter body. The quotient found by dividing the absolute weight of the light substance by the weight of the fluid it displaces will be its specific gravity, which must of necessity be less than unity.

A piece of white wax weighed 50 gr. $= W$
" copper " 388 gr. $= W'$
Weight of the two substances = 438 gr. $= W + W'$
lost on immersion by the two = 95·8 gr. $= w + w'$
" " copper = 44·2 gr. $= w'$
" " wax = 51·6 gr. $= w$

∴ the specific gravity of the white wax is

$$s = \frac{W}{w} = \frac{50}{51{\cdot}6} = 0{\cdot}969$$

If the substance be of such a nature as readily to imbibe the water on account of its porosity, as, for instance, most species of wood, the following is the course adopted: — The

the same mass at its maximum density, multi
number expressing the v at the particular tempe

Table IX.

Of the Specific Gravities of some of the most im

(The density of distilled water is reckoned in this Tab
38¾° F. = 1·000).

Name of the Body.	Specific Gravity.
I. SOLID BODIES.	
A. Metals.	
Antimony (of the laboratory)	- 4·2 — 4·7
Brass -	- 7·6 — 8·8
Bronze for cannon, according to Lieut. Mallet -	- 8·414 — 8·974
Do. mean -	- 8·758
Copper, molten	- 7·788 — 8·726
Do. hammered	- 8·878 — 8·9
Do. wire-drawn	- 8·78
Gold, molten	-19·238 — 19·253
Do. hammered	-19·361 — 19·6
Iron, wrought	- 7·207 — 7·788
Do. cast, a mean	- 7·251
Do. grey -	- 7·2
Do. white -	- 7·5
Do. for cannon, a	[illegible]

Name of the Bo
Do. Bohemian Saxon -
Do. English
Zinc, molten
Do. rolled -
B. Building Stones.
Alabaster -
Basalt -
Dolerite -
Gneiss -
Granite -
Hornblende -
Limestone, vari kinds -
Phonolite -
Porphyry -
Quartz -

TABLE IX. — *continued.*

f the Body.	Specific Gravity.		Name of the Body.	Specific Gravity.
	Fresh-felled.	Dry.	moist sand -	2·05
			gravelly soil -	2·07
am - -	0·9452	0·7695	clay - -	2·15
hesnut -	0·8614	0·5749	clay or loam,	
- -	0·9206	0·4735	with gravel -	2·48
- -	0·8170	0·4390	Flint, dark - -	2·542
- -	0·9036	0·6592	Do. white - -	2·741
- -	1·0494	0·6777	Gunpowder, loosely	
other speci-			filled in —	
- -	1·0754	0·7075	coarse powder -	0·886
Pinus Abies			musket do.	0·992
- -	0·8699	0·4716	Do, slightly shaken	
nus Sylvestris	0·9121	0·5502	down —	
(Italian) -	0·7634	0·3931	musket-powder	1·069
- -	0·7155	0·5289	Do. solid - -	2·248 — 2·563
ite - -	0·9859	0·4873	Ice - - -	0·916 — 0·9268
			Lime, unslacked -	1·842
RIOUS SOLID			Resin, common -	1·089
BODIES.			Rock salt - -	2·257
al, of cork -	0·1		Saltpetre, melted -	2·745
ft wood -	0·28 — 0·44		Do. crystallised -	1·900
k - -	1·573		Slate-pencil -	1·8 — 2·24
- -	1·232 — 1·510		Sulphur - -	1·92 — 1·99
- -	1·865		Tallow - -	0·942
common -	1·48		Turpentine - -	0·991
gh sand -	1·92		Wax, white - -	0·969
gh earth with			Do. yellow - -	0·965
gravel -	2·02		Do. shoemaker's -	0·897

II. LIQUIDS.

cetic -	1·063	Ether, acetic -	0·866
uriatic -	1·211	Do. muriatic -	0·845 — 0·874
itric, concen-		Do. nitric - -	0·886
d - -	1·521 — 1·522	Do. sulphuric -	0·715
lphuric, Eng.	1·845	Oil, linseed - -	0·928 — 0·953
oncentrated		Do. olive - -	0·915
rdh.) - -	1·860	Do. turpentine -	0·792 — 0·891
ol, free from	0·792	Do. whale - -	0·923
r - -		Quicksilver -	13·568 — 13·598
mmon -	0·824 — 0·79	Water, distilled -	1·000
niac, liquid -	0·875	Do. rain - -	1·0013
ortis, double -	1·300	Do. sea - -	1·0265— 1·028
ngle - -	1·200	Wine - -	0·992 — 1·038
- -	1·023 — 1·034		

III. GASES.

	Water = 1. Temp. 38¾° F.	Barometer 30 In. Temp. = 34°.		Water = 1. Temp. 38¾° F.	Barometer 30 In. Temp. = 34°.
spheric air =					
=	0·00130	1·0000	Hydrosulphuric acid		
nic acid gas -	0·00198	1·5240	gas - -	0·00155	1·1912
nic oxide gas -	0·00126	0·9569	Muriatic acid gas -	0·00162	1·2474
reted hydro-			Nitrogen - -	0·00127	0·9760
, a maximum -	0·00127	0·9784	Oxygen - -	0·00143	1·1026
rom coals - {	0·00039	0·3000	Phosphureted hy-		
	0·00085	0·5596	drogen gas -	0·00113	0·8700
ine - -	0·00321	2·4700	Steam at 212° F. -	0·00082	0·6235
Iodic *gas* -	*0·00577*	4·4430	Sulphurous acid gas	0·00292	2·2470
gen - -	*0·0000895*	688			

elastic and non-elastic [illegible]
found. Again, as a general rule, gases
for the most part colourless, and consequ
distinguished from all other bodies by th
sity and their low specific gravity.

Aeriform bodies are divided into
sible gases, and *vapours*. To the firs
unchanged their aggregate form,
volume when the force by which the
operate, whatever may have been th
or the degree of compression to wh
They are the only *perfectly elastic*
ence: they are oxygen gas, nitroge
for modern research has shown that
previously been reckoned as belong
really permanent gases; as, *ex. gr.*,
ric-acid gas, ammoniacal gas, &c.,
fluid, nay, even to a solid, form.
which the last-named are example
action of cold and compression, lo
is uncertain whether or no the at
for it has been said by means
have been reduced to a liquid. A
as vapours, which, at an ordinar
at a mean temperature, lose th
vapours exhibit many peculiariti
the gases, the fuller account of w

§ 181.

very fluid, whose atoms, by virtue of their predominating ; of repulsion, have a tendency to fly further from each other, t necessarily expand so as to occupy a continually larger e, until it meets with some obstacle that limits its further ex- ion, or till some counteracting force cancels its tendency to and.

quilibrium, or rest, can therefore be established in aeriform ies only when their further extension is checked on every side some boundary, or when a force of compression or attraction ; upon them equal to their own force of expansion.

ls every liquid exerts a pressure on the sides of any vessel taining it, so elastic fluids exert a similar pressure in all ections upon the surfaces by which they are bounded; this ssure is equal in all directions, and proportional to the force of pansion. If the resisting medium offer an equal resistance on sides, the gas, by virtue of this eccentric expansibility, will ume a spherical form.

Soap-bubbles, and the small bubbles which rise in water, have invariably a globular figure, and show the eccentric expansibility of atmospheric air.

If the boundary of the solid which limits the gas does not en- rge with it, or if the force of the latter exceed the solid's co- sion, then disruption takes place, and the gas escapes in that rection where the rupture happens. If, on the contrary, this undary be subjected to an external pressure equal to and con- mporary with that which it suffers from within, these two forces unteracting each other, no escape will be allowed to the gas, owever thin and weak the solid itself may be.

§ 182.

All these fluids are in like manner susceptible of *compression* § 179.); *i. e.* by means of some external force the repulsion sub- isting between their particles may be overcome, and their mass educed to a smaller volume. The component atoms will con- equently be brought closer together, and their mutual repulsion rill be increased; *i. e.* the expansive force and the density of the luid increase in the same proportion as the compression. When he external force ceases to act, the tendency of the fluid to ex- and developes itself uncontrolled, and this impulse is obeyed till t again fills its former space, and its expansive force recovers its quilibrium.

§ 183.

If an elastic fluid, in addition to the action of its molecular forces, be subjected *to an attractive* force from some other body

be denser, and this density will dimini
the attracting body increases.

Hence it follows that the denser fluid h
force, and that this force is always propor
the strata above, since through the attr
above-named pressure and the force of ex
in equilibrio the one to the other.

§ 184.

Every change in the expansive force, or
be brought about by some external cause,
will disturb the equilibrium subsisting b
forces, and produce motion in such an at
scribed; this motion will last till the rep
particle is restored to equilibrium with all
and press upon it.

II. PHENOMENA OF ATMOSPHERIC A
ITS COMPRESSIBILITY AND E

§ 185.

The *atmospheric air*, as being the most
bodies, may be taken as the representati
is to this form of bodies what water i
exists all over the world, we can most
noticed in the preceding sect

[illegible] ways by its [illegible] hurricanes [illegible] gth as often [illegible] s.

The [illegible] of the air is of [illegible] in communicating motion to wind-mills, ships, &c. [illegible]

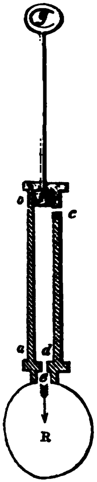
[illegible]

ur atmosphere is compressible and elastic. By [illegible] rnal force it may be condensed [illegible] smaller e. Any further condensation [illegible] increasing roportion to the condensation already effected [illegible] ch it is compressed [illegible] again [illegible] e it originally filled. This expansion [illegible] force t is in inverse proportion to the space [illegible] and if the surnding bodies are not able to withstand the expansion, they will put in motion with a greater or less velocity.

Our daily experience proves that these properties are possessed by the air; as, *e. gr.* the compression and expansion of a bladder when the air is forced out of it, as also the air-cushions and pillows with the use of which we are familiar.

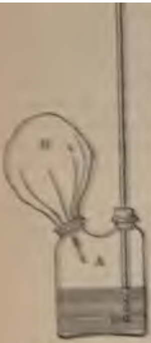
To increase the density of air in a given space we make use of a *condensing syringe* or *pump*. It consists of a small hollow metal cylinder, *c b*, *fig.* 103, in which a metal piston rod having an air-tight piston, *f*, works. At the lower end of the tube is a small aperture, *e*, in which a valve of leather or bladder, *e*, closes; this part of the apparatus screws into a receiver, R, in which the air is to be condensed. If *f* be depressed by means of the piston-rod *g f*, to *d*, the air being forced down opens the valve *e*, and rushes into R. Now draw up the piston, and the pressure of the air against the valve *e*, since it opens downwards, will prevent the escape of any air from R; when *f* has again arrived at *h*, a fresh charge of air rushes in at an opening, *o*, made for this purpose in the cylinder. By continually repeating the process already described, the air is more and more condensed in R. Condensing syringes of this kind are used in charging air-guns.

Fig. 103.



The following may serve as instances of motion generated by the compression of the air.

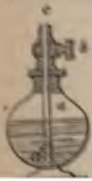
First Exp. A liquid may be forced to a *considerable* height up a tube by means of the



the air in the bladd
seen to mount up t

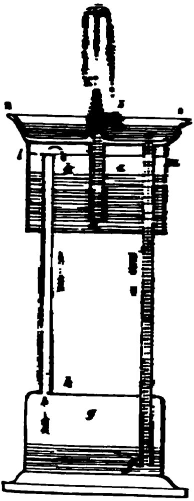
Second Exp. He
of this apparatus a
forced up through
by the compression
struction is, for the
below: — A hollo
from which the ex
cluded by turning
tube, *c d*, that reach
of the globe, and
screw. Fill the
up with water, scre
breathe through
turned; the breatl
ascend through the water, and ming
already there in the space *a*, will p
the fluid with a gr
So long as the cock
breath is driven, rem
cannot escape; but o
fluid finds vent in a
greater compression
duced, and conseque
if the condensing
screwed on, and th
by it.

Fig. 105.



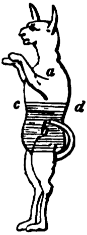
lower one, g: the [illegible] [illegible] [illegible] from the top of the [illegible] vessel. [illegible] [illegible] [illegible] the lid of the [illegible] one. [illegible] [illegible] [illegible] [illegible] that the air [illegible] [illegible] [illegible] [illegible] [illegible] of the [illegible] through which the [illegible] [illegible]. The upper vessel is first filled with water through c, the stop-cock having been previously [illegible] off. When the vessel is full the cock must be [illegible] and the [illegible] [illegible] [illegible]. Now pour water into the basin so that [illegible] in the upper [illegible], the fluid will find its way into the lower vessel at g through the tube e f. By this means there is exerted on the air in g, above the fluid, a pressure proportional to the height e f of the column of water [illegible]. The air thus compressed rises through h l into the upper vessel, transmitting the pressure, as in the Hero's Ball, to the water in it, which is forced out at i in a column whose height is proportional to the height of e f. The fluid discharged by the jet is received in the basin a a, whence it again descends the pipe e f to g, thus maintaining an uninterrupted jet-d'eau so long as there is water in a.

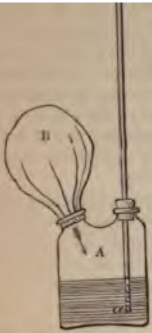
Fig. [illegible].



Fourth Exp. The Cartesian Devil. This is a well-known glass figure, constructed, as *fig.* 107. shows, so that it may float in a vessel of water above whose level a small portion of air is confined, in such a manner that if this air be compressed, the figure will immediately descend, and rise again to the surface when this force ceases to be exerted. This is thus contrived: in the middle of the figure *a* is a capillary tube *b*, through which so much water is admitted into the interior of the body that its specific gravity is little less than that of the water it is to float in. Having thus adjusted it, the figure is to be immersed in a wide-mouthed glass over which a piece of bladder has been strained, in order to con-

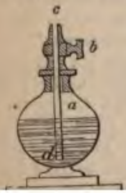
Fig. 107.





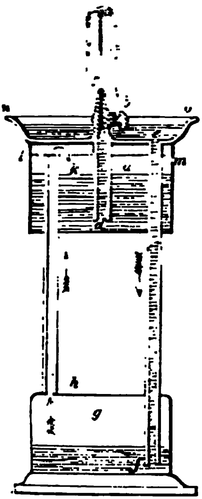
the air in the bladder,
seen to mount up the
Second Exp. *Hero's*
of this apparatus a flui
forced up through a
by the compression of
struction is, for the mo
below: — A hollow
from which the exter
cluded by turning a
tube, *c d*, that reaches
of the globe, and fit
screw. Fill the vess
up with water, screw
breathe through *c*,
turned; the breath o
ascend through the water, and minglin
already there in the space *a*, will press
the fluid with a great
So long as the cock *b*,
breath is driven, remair
cannot escape; but on i
fluid finds vent in a jet
greater compression of
duced, and consequentl
if the condensing syı
screwed on, and the
by it.
On this principle de

Fig. 105.



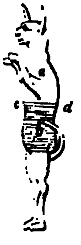
lower one, *g*: the second, *h k*, reaches from the top of the lower vessel, and terminates just below the lid of the upper one. Care must be taken that the air is not admitted at those parts of the cisterns through which the pipes pass. The upper vessel is first filled with water through *c d*, the stop-cock having been previously taken off: when the cistern is full the cock must be replaced, and the external air excluded. Now pour water into the basin *n o*, that fits on the upper cistern, the fluid will find its way into the lower vessel at *f*, through the tube *e f*. By this means there is exerted on the air in *g*, above the fluid, a pressure proportioned to the height, *f e*, of the column of water (§ 158.). The air thus compressed rises through *h k* into the upper vessel, transmitting the pressure, as in the Hero's Ball, to the water in it, which is forced out at *c* in a column whose height is proportional to the height of *e f*. The fluid discharged by the jet is received in the basin *n o*, whence it again descends the pipe *e f* to *g*, thus maintaining an uninterrupted jet-d'eau so long as there is water in *a*.

Fig. 106.



Fourth Exp. The Cartesian Devil. This is a well-known glass figure, constructed, as *fig.* 107. shows, so that it may float in a vessel of water above whose level a small portion of air is confined, in such a manner that if this air be compressed, the figure will immediately descend, and rise again to the surface when this force ceases to be exerted. This is thus contrived: in the middle of the figure *a* is a capillary tube *b*, through which so much water is admitted into the interior of the body that its specific gravity is little less than that of the water it is to float in. Having thus adjusted it, the figure is to be immersed in a wide-mouthed glass over which a piece of bladder has been strained, in order to con-

Fig. 107.

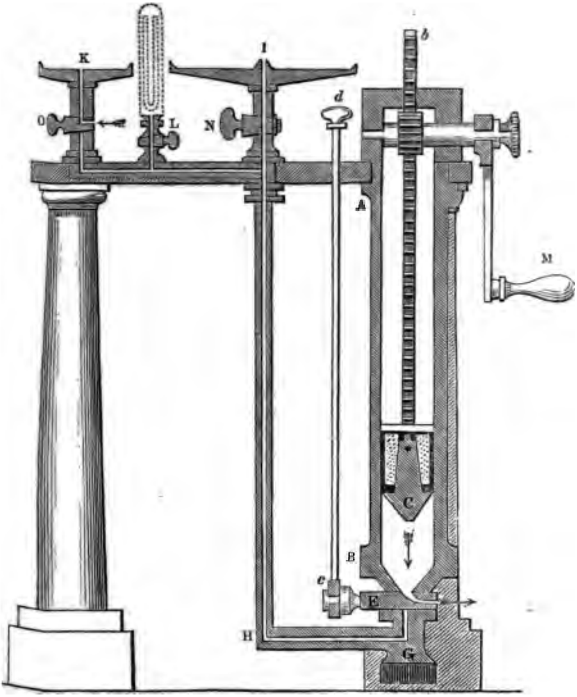


forced out of the barrel
to the bottom of the barrel. Again reve
cock; and as often as the operation just des
air still in the receiver will be continually
maining, as also that discharged at each str
stantly diminishing.

Repeated attempts have been made
to still higher degrees of perfection s
von Guericke, burgomaster of Magdeb
this machine in 1560, when he exhibit
Ferdinand III. his famous experiment
hemispheres. Self-acting valves, ope
the elastic force of the air, have been
the manipulation of which is tedious.
given to the air-pump instead of one, so
and more rapid rarefaction of the air
piston in one barrel being made to asc
descends. The most serious defect
that the atmospheric air could not be
the barrel, but that it remained betw
barrel in the space *gr*, *fig.* 108. Th
filled with air of the ordinary density
piston, as contact between the latter
cylinder does not take place; when
the communication re-established wit
tion of air forces its way in and di
rarefaction already attained. If the ai
rarefied, that one stroke of the pisto
quantity as equals the air contained

depressed by means of a cog-wheel that is turned by the handle M. If a thin film of oil be poured on the upper surface of the piston the friction will be lessened, and the whole will be rendered more perfectly air-tight. To diminish to the utmost the space between the bottom of the barrel and the piston-rod, the form of a truncated cone is given to the latter, so that its extremity may be brought as nearly as possible into absolute contact with the cock E; this space is therefore rendered indefinitely small, the oozing of the oil down the barrel contributing still further to lessen it. The exchange-cock E has the double bore already described, and

Fig. 110.



$\frac{31{\cdot}32}{25056}$ gr. = $\frac{1}{800}$ By the sa
found that 25056 gr. of wate
space left vacant by the air if
water: so that by either process

The air is of unequal density, an
partly by its own pressure, partly by
it contains, but chiefly by variations i
must be had to all these circumstance
gravity of the atmosphere. By caref
tion it has been ascertained that at a
a mean pressure, the air is 800 tim
at the freezing point it is only 770
portions being known, the absolute v
may readily be estimated.

From the above remarks it is
lation of the specific gravity of a
some little difficulty. Biot and
accurate experiment, that with
obtains at the level of the sea, (
as will be hereafter shown, with
and at the temperature of fre
or $\frac{1}{770}$ th nearly, the weight of wa
39° F. its density is nearly $\frac{1}{810}$th

Since 1 cubic foot of pure wat
= 911·5 oz. troy - - -
1 cubic foot of

volume. Call V = 1 the volume of the air at 32°, then at
°,

$$V = (1 + \cdot00208\,t)$$

Next let S, s, represent the specific gravities or densities of similar masses, which, of course, are inversely to their volumes (§§ 4. and 31.) whence

$$S : s :: v : V,$$

and consequently the specific gravity of air at any temperature whatever, is

$$s = S\,\frac{V}{v}$$

But at the normal temperature 32°, $S = \frac{1}{770}$ and V = 1, whence

$$s = \frac{1}{770\,v}$$

For t assume 132°, then

$$s = \frac{1}{770\,(1 + \cdot00208 \times 100)} = \frac{1}{930\cdot16}$$

n like manner the specific gravities of other gases may be
id, by admitting them into a flask from which the common
has been entirely exhausted, and then ascertaining the
ght. In such cases the specific gravity of dry atmospheric
t its greatest natural density is assumed as unity; the tem-
ture being that of the freezing point and the barometer
ding at 30 inches.

Suppose now that the quantity of dry atmospheric air pumped out of the flask was 20 gr., that a gas was then introduced weighing 30 gr., its specific gravity will be thus expressed: $\frac{30}{20} = 1\cdot5$.

§ 193.

ince our atmosphere, as has been shown already, is a pon-
ous elastic fluid, it must display the same peculiarities as we
ame acquainted with in liquids, modified, however, by its
pressibility and expansibility.

y virtue of its weight the atmosphere exerts a pressure not
ely on all bodies below it, but also on its own subjacent par-
es. The absolute amount of this atmospheric pressure was
discovered by Torricelli (1643), a pupil of Galileo.

First Exp. Fill a tube about 32 inches long, and from 2 to 3 lines wide, with mercury, the other end being either secured by an iron cock, or else by its being hermetically sealed. Close the open end by pressing against it with the finger, invert the tube and plunge the open end into a cistern of mercury; remove the finger, and the metal will not escape, but remain at a height nearly 30 inches above the level of the quicksilver in the cistern.

the mercury forms with the cistern
communicating tubes, in which the mer
expected to stand at an equal height i
observe that the atmospheric air rests on t
silver in the cistern, whilst there is a va
fills the tube. To this circumstance we
of the mercury in the tube to a height
inches above the level of that in the cis
accurate explanation the following experi

Second Exp. Open the tube at
upon the quicksilver, which will sink
the tube as without it.

The atmospheric air consequently pre
and indeed upon all other bodies, with a
tain the quicksilver in the tube at a hei
inches, whence *this pressure must be equal*
of mercury whose base is equal to the surfa
height about 30 *inches.* — The force thus
whatever is called *the Atmospheric Pressu*

Throughout Germany the mean
28 Paris inches; in France it is esti
=28·075404 Paris inches; in Englan
28·1457 Paris inches; all which a
one from another.

The body of a man of ordinary
about 2000 square inches, whence t
square inch will be 30,000 lb. — Re
on the surface of the earth. — Eac

opposite extremity of the tube has been immersed in a vessel of water the fluid will fill the tube.

§ 194.

The atmosphere can exert this pressure only if no other force counteract it. If the counter-force be exactly equal to the weight of the air, no effect is produced; if it be less, the atmosphere presses with a force equal to the difference of the forces. The pressure is perceptible only when it acts in one direction, *i. e.* when there is a vacuum on the opposite side of the body to that on which the air presses.

The following experiments illustrate this fact.

First Exp. Lay the hand on a cylindrical receiver open at top, exhaust the air, and it will be firmly held down by the superincumbent air. — For a similar reason, concave bodies hang to the lips when the air is withdrawn by means of the mouth. This furnishes us with one means for testing the density of air in an imperfect vacuum.

Second Exp. The receivers are firmly fixed to the plate of the air-pump entirely by the external pressure which is not counteracted by the rarefied air within them.

Third Exp. The force of the atmospheric pressure is most strikingly shown in the *Magdeburg hemispheres.* They are two hollow hemispheres of brass or copper, whose edges fit accurately, each hemisphere being furnished with a strong ring or handle, one of them also having a tube, that fits into the screw-hole of the plate, and a cock to shut off the communication. — Place the hemispheres one on the other, exhaust the air, turn off the cock, unscrew it from the pump, put on the handle, and it will be found that a great force is requisite to separate the apparatus. If now the superficial content were 100 sq. in., and the height of the mercury were 30 inches, then the pressure would be exactly 100 × 14·75 = 1475 lbs. = 13 cwt. 0 qr. 19 lb. If now the greatest force that a horse can exert for a short time be 700 lbs., it would require 2 horses to pull the hemispheres asunder. — In Guericke's experiment, referred to above, there were successively from 14 to 30 horses harnessed to the hemispheres, which were 2 feet in diameter, without effecting a separation; when more horses were added, the hemispheres parted with a loud report.

Fourth Exp. Tie a piece of bladder tightly over a low glass cylinder about 4 inches across; extract the air quickly, and if the bladder be well dried it will be torn asunder by the pressure of the air with a loud noise.

If the top of the glass be covered with a thin plate of glass, a similar consequence will ensue.

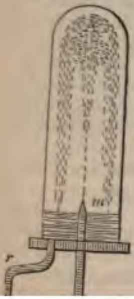
the receiver of
it discharge son
small vessel, its
to cease when rarefaction has been
enough.

Fourth Exp. If a syphon be concealed
one of its openings being within the cu
tom, whilst the other, which is lower,
and liquor be poured into such a cup, it
fluid rising to a height equal to the l
leg, that the contents of the cup will e
is owing to the fact, that the syphon, ob
regulate vessels that communicate, co
fluid: if the fluid do
as the syphon, the cup
On this principle the
Diabetes Heronis, is cons
of Languedoc, or *Canal*

It is probably owing
that some springs are in
standing water and po
come drained when th
particular height.

Fifth Exp. By the
we may make a *Syph*
Syphon. Its constructi
A, *fig.* 126., is a glass
and fitting closely on

Fig. 126.



he shorter tube into the glass A, whilst it escapes at the ame time through the longer. By the discharge of the vater through rs a vacuum is created in A; the pressure f the air within is less than that of the atmosphere resting n the fluid in the glass, whence it rises up the tube nm.

e pressure of the atmosphere, transmitted as it is in all di- ns, prevents the efflux of liquor from a small aperture in a unless the pressure be admitted to the surface of the fluid. is a fact abundantly confirmed by experience, and in accord- with which several useful pieces of apparatus have been con- ed. The following experiments may still further illustrate observations.

The *vent-peg* is raised in order to admit the air to the sur- ace of any liquor which it is wished to draw off from a ask.

By means of the atmospheric pressure water (and other iquids) may be kept in full vessels, whether the aperture in he vessel be large or small, care only being taken that the pening shall be under water: other gases, besides common ir, are thus introduced into receivers.

The *pneumatic trough* is a vessel of wood or lead, of either n oval or oblong form (*fig.* 127.): it has a moveable stage r *bridge*, *bb*, above which the water is to be poured to the eight of about an inch; in the middle of the bridge is a und hole *o*, communicating with an inverted funnel *t*, under hich the tube *gs* is brought, that conveys the gas it is ished to collect. Bell-shaped glasses filled with water are aced above the hole in the bridge. The gas passing through e tube at *s* into the water, ascends the receiver F in the rm of air-bubbles, and expels the water thence. In order preserve the gas, it is advisable not to fill the receiver quite ll; a small quantity of water left at the bottom of the re- iver, will cut off the gas from communication with the

Fig. 127.

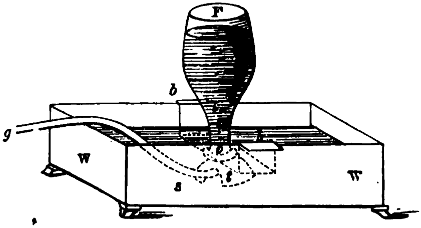
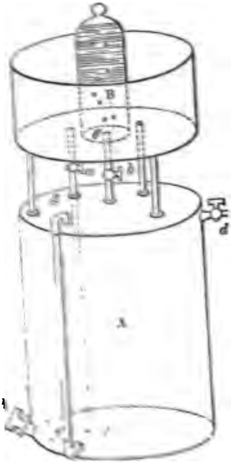


Fig. 128.



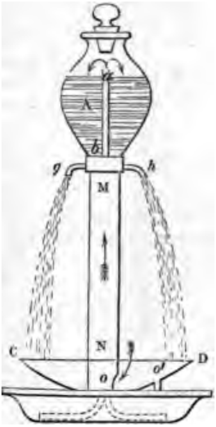
A is a cock d, through which th
be drawn off, whilst the apert
near the bottom of the vesse
which the gas is cond

Insert the tube proceeding from the retort, or other vessel whence the gas is obtained, into the gasometer at this opening, and as the bubbles of gas rise to the top of the water in B, they will expel the latter at *h*. When the gauge shows that a full supply has been obtained, take out the tube and secure the aperture *h*. The gas may now be taken off either at *d* or *e*; if at the latter point, in jars, as B, previously charged with water. To cause the gas to ascend, water must again be poured into the upper cylinder, and the communication *a* be re-opened, if you intend to take it off at *d*; if you prefer taking it in a receiver at B, open the cock *e*.

Sixth Exp. Fill a glass to the brim with water; cover it with a sheet of sufficiently stiff paper, so as to exclude the air from entering into the glass; press the paper firmly against the rim; invert the glass quickly; remove the support, and both paper and water will be supported by the upward pressure of the atmosphere.

Seventh Exp. Kirchner's Intermittent, or *Magic Fountain.* — It consists of a hollow glass globe (A, *fig.* 129.), having a a neck into which a ground-glass stopper fits accurately; at bottom it has a rim of brass, in which are several holes. This rim is surrounded by a second outer one, having two, or at most four, short fine tubes, *g* and *h*, so placed that by turning the globe round they may be connected with the corresponding holes in the inner rim, or the communication be interrupted at pleasure. Through the inner rim a tube, *a b*, passes, open at both ends, reaching almost to the stopple, whilst it empties itself below into the pipe M N, whose foot is fixed in the dish C D; in this pipe is a small lateral opening *o*; about the middle of the dish is the little tube *o'*. To make this apparatus play, the globe is turned so that the communication is cut off with the tubes *g* and *h*, the glass is filled with water, and the stopple put in. Now move the globe so that the openings in the inner and outer rims shall correspond: the water will immediately begin to issue from

Fig. 129.



weight of the superincumbent strata.

a. If a vessel be closed air-tight at the foo mountain, and the stop-cock be opened on ar summit of the mountain, the air will rush out o —Explain this phenomenon.—If the vessel b like manner at the top of the mountain, and reaching its foot, the external air will rush into t Why?

§ 198.

Experience teaches us that the height of the m Torricellian tube varies at the same place. Since th mercury in such a tube measures the intensity of pressure (§ 196.), it follows that these variations in th the column denote corresponding changes in the air's elasticity. When the density and elasticity of the at increased, the quicksilver must rise; when they are it must sink.

In order to measure accurately the height of the the variations in it, some unit of length is applied a of the tube. A Torricellian tube, provided with su called a barometer, or weather glass; the *height of th* the height of the column of mercury accurately m cording to the scale: by the *mean height of the baro* particular place is understood the arithmetical me number of different altitudes observed at that place.

In Germany the old French standard, or Par

2. The *Common Barometer* (*fig.* 134.) is a Torricellian tube, whose open end being turned up, has a spherical form. The globe performs the office of the cistern described in the other barometer; the scale is graduated from the same point in both these instruments.

Fig. 133.

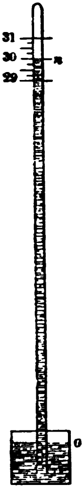
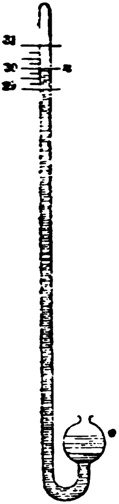
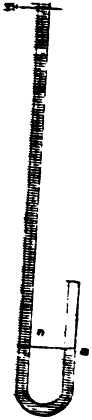


Fig. 134.



As in barometers of this kind the distance *o n* of the two surfaces of the mercury is the height of the barometer, it follows that the scale must begin at *o*, the level of the quicksilver in the cistern or bulb. If it do so at any particular height of the mercury, yet it will no longer coincide when the column rises or falls in the tube, as a rise or fall must also take place in that which is contained in the cistern. By making the cistern very wide as compared with the tube, these changes in the level of the cistern are rendered almost imperceptible under ordinary circumstances, so that for common purposes the variation in the level may be disregarded; if accurate measurements are required, the level of the mercury in the cistern must be regulated by some such mechanical contrivance as Fortin and Horner have invented. In the common barometer these differences



equal width, at l
in the height of t
difference between
and shorter legs
—As the open le
the closed one, t
equal in both, whi
it is indispensabl
the altitude of th
change of level in
most convenient and
this is to adjust a
the two legs prior
that its zero may
of the mercury in t

Different contriva
to render the minu
mospheric pressure,
the height of the b
perceptible by emb
which devices must impair the exa
length of the column. Of these we
Diagonal, and Hook's Wheel-baromete
gen's Double-barometer.

Essential properties of a good barom
purity of the mercury, which is effecte
rate graduation of the scale, to which
be added

consequently be reduced to one standard temperature. For this purpose, it will be most accurate to assume 32°. The most exact experiments of Dulong and Petit have fixed the expansion of the mercury in the barometric tube at $\frac{1}{9990}$ of its volume with every additional degree of heat, and a corresponding contraction for each degree of heat that may be deducted: thus the increased altitude of the column caused by the heat for T degrees above the freezing point must be deducted from the height as shown by the barometer, and for T degrees below that point it must be added to it. Hence we have the following formula by which to correct the barometer: —

$$b = B\left(1 \pm \frac{T}{9990}\right) = B\,(1 \pm 0{\cdot}0001001\ T)$$

B being the altitude observed, T the temperature of the mercury, and b the correct altitude.

§ 200.

The barometer may be used not only to measure the pressure of the free or natural atmosphere, but also to determine the density and expansive force of any other gas.

For this purpose, it is the most convenient and exact guage for showing the degree of rarefaction attained in the receiver of an air-pump; applied to this purpose, it is called a *Barometer-guage.* — The object proposed can be attained in two ways; either the external pressure of the atmosphere can be made to drive the mercury up the tube till the desired degree of exhaustion has been reached, or the column in the guage may be made to sink as the exhaustion proceeds. In the former case, the difference between the altitudes of the barometer and that of the guage shows the density of the rarefied air; and in the latter the guage itself shows it. The degree of rarefaction is found by dividing the altitude of the barometer by that of the guage: thus, if the barometer stood at 30 inches, whilst the guage stood at 1 inch, the air would have been rarefied thirty times; if it stood at a line, then the air has been rarefied 360 times.

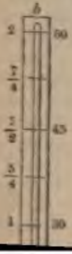
A barometer of the first-named sort consists of a glass tube about 33 inches long, its upper end communicating with the receiver that is to be exhausted, whilst the lower is plunged in a cistern of mercury. The scale commences from the level of the mercury in the cistern. — These guages are liable to the same source of error that was noticed in the cistern-barometer. (§ 199.)

The other, generally known as the *Syphon guage*, *fig.* 111., is a shorter syphon-shaped barometer, about six inches in

of the column in the guage, the difference
in the two legs will express the degree of ra
tained. Such a guage is either placed beneath
of the pump, or, as is more convenient, it is
receiver of its own, as in *fig.* 111., which, duri
ration of the air-pump, *fig.* 110., is connected
the cock L with the receiver and with the co
pipe of the machine.

In order to determine the pressure or expansive f
by the aid of the barometer, they must be inclosed in
a column of mercury made to act upon them in the
atmosphere itself. The quicksilver which is containe
legs, as being in vessels that communicate, would
equal height in both; but as the gas or vapour un
ation is made to press on the free surface of the me

Fig. 136.

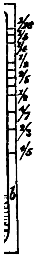


open leg, it will drive the merc
until its column holds the gas
— The *steam-barometer* or *mano*
chiefly to measure the force of
boilers.

Fig. 136. is a representation
barometer. A is a steam-tight
taining quicksilver; *a* is a tu
cating with the boiler, throug
steam flows and presses on th
The barometer tube *b c*, open a
nearly to the bottom of A, ha
to it a scale whose zero point

lariotte's Manometer is shown in *fig.* 137. The surfaces of the mercury *a* and *b* will stand at the same level so long as no steam is admitted. In the space *b c* above the quicksilver is some air of the ordinary density, the tube at *c* being hermetically sealed. The steam is admitted at *d*, and so pressing on the surface *a* of the mercury forces it above its natural level *b*, and compresses the air in *b c*. The scale from *b* to *c* marks the force of compression in atmospheres. The greater width of the tube at *a* is therefore necessary, in order that the level at *a* may not be materially affected by the ascent of the mercury above *b*, *a* being assumed as the zero of the scale. Instead of this construction, that represented in *fig.* 136. may be adopted if the tube *c b* be hermetically sealed at *b*, and the scale be graduated according to Marriotte's law.

37.



§ 201.

ges in the altitude of the barometer at the same place *regular*, and in part extremely *irregular*. The regular ccur almost always at the same time of day, attaining *inima* and two *maxima*. They show an ebb and flow the atmosphere, similar to what we observe in the sea. ey are very small, the oscillation seldom amounting to a line, and for the most part observable only in the . The irregular changes in its altitude are much degree than the regular, and also are more frequent ble as we approach the poles; for which reason less id by us to the regular alterations in the height of the

greatest depression of the barometer occurs daily 4 A. M. and P. M., and its highest elevation about . and P. M. In summer these extreme points are d from 1 to 2 hours earlier in the morning, and as later in the afternoon.—The greatest changes at Peru only to a few lines, whilst in Germany they amount m 2 to 3 inches, and further north they even exceed st measure.

se of the irregular changes in the barometer's altitude erate and frigid zones, appears to be principally the riation in the wind, which is produced by the altera- n the temperature and form of aggregation of the hy- nbined with the atmosphere: these changes are more e during the winter than during the summer months.

contracts till it becomes condensed into the liqu descends to the earth as rain. The cause of thi aggregation is to be found in the alteration of and the winds generated by this alteration. Th great part of western Europe it may be assumed rule, that south winds, which are mostly warm produce the lowest, and north winds, which usu and dry, produce the highest elevation of t whilst its mean altitude shows that the wind blo intermediate quarter between N. and S. A ch wind is attested by sudden oscillations in the column; stormy weather sometimes causes ascent of the mercury, but more commonly a depression. Successive rising and falling of frequently precedes showery weather. A consi vation of the column, however, is not invariably dry, nor is a low state of the mercury an indubit of a moist state of the atmosphere, as both the the atmosphere and the nature of the weather affected by currents of air; so although the used as a *weather-glass*, it cannot in this char plicitly relied on.

§ 202.

Since the altitude of the barometer depends on t the atmosphere, and this force again is affected by the column resting upon it, it is clear that a short air will exert a less pressure and sustain a less colum that only a shorter column of mercury will be sustained by it. Analogous conclusions may be drawn if the process be reversed; the height of the barometer will be increased by descending from a greater elevation to a less.

It is well known that the surface of our earth is not uniform, consequently it does not sustain an equal column of air at all points, whence the mean altitude of the barometer (§ 199.) will vary at different places; for similar reasons this altitude gradually increases at the level of the sea from the equator towards the poles. (a)

As has been remarked above, *a very important application of the barometer is measuring the heights of mountains.*

Since the length of the mercurial column invariably depends on and is proportional to the atmospheric pressure, if we know the law by which the altitudes increase, we can determine the difference between the elevations of two places, their mean barometric altitudes being given; or, this difference may be found by observing simultaneously the heights at which the mercury stands at the two stations. Now it has been demonstrated mathematically that *the pressure of the atmosphere decreases in a geometrical progression, as the height of the place of observation increases in an arithmetical progression.* (b)

In order to measure the height of any place by means of the barometer, the altitude of the mercury must be accurately observed simultaneously at both the lower and upper stations, the logarithms of these two barometric altitudes found, and the less be subtracted from the greater. The difference will be proportional to the difference of the elevations of the two points; and in order to express this last difference in some known measure of length, the logarithmic difference must be multiplied by a constant number previously found both by practice and theory for the various measures of length. — The same process must be gone through if the mean barometric altitudes of the two stations are given.

If great accuracy be required, the calculation becomes more complex, as allowances must be made for the influence of temperature both upon the mercury and the atmosphere; beside which, regard must be had to the degree of moisture in the air, as well as to the irregular variations in the height of the barometer at the places of observation. The improved construction of instruments, and the exact formulæ deduced from mathematical investigation have rendered this method easy of application, and comparatively free from error.

a. The following heights of the barometer taken at the level of the sea for the various degrees of latitude, the temperature being 32° Fahr., may be considered as tolerably exact approximations, according to Munke's experimental and theoretical observations; many anomalies may still be

	11	670·6	1·43		11	1219·7
	10	684·7	1·44		10	1236·1
	9	699·1	1·44		9	1252·6
	8	713·5	1·44		8	1269·1
	7	727·9	1·45		7	1285·6
	6	742·6	1·45		6	1302·1
	5	757·0	1·46		5	1318·9
	4	771·6	1·46		4	1335·6
	3	786·2	1·47		3	1352·4
	2	800·9	1·48		2	1369·3
	1	815·7	1·48		1	1386·3
23	0	830·5	1·49	20	0	1403·3
22	11	845·4	1·50	19	11	1420·5
	10	860·4	1·50		10	1437·7
	9	875·4	1·51		9	1455·0
	8	890·5	1·50		8	1472·3
	7	905·5	1·51		7	1489·7
	6	920·6	1·52		6	1507·1
	5	935·9	1·52		5	1524·7
	4	951·1	1·53		4	1542·4
	3	966·4	1·53		3	1560·0
	2	981·7	1·55		2	1577·7
	1	997·2	1·55		1	1595·6
22	0	1012·7	1·56	19	0	1613·6
21	11	1028·3	1·56	18	11	1631·6
	10	1043·9	1·57		10	1649·7
	9	1059·7	1·57		9	1667·9
	8	1075·4	1·58		8	1686·2
	7	1091·2	1·58		7	1704·5
	6	1106·9	1·60		6	1722·8
	5	1122·9	1·60		5	1741·4
	4	1138·9	1·60		4	1760·0
	3	1154·9	1·61		3	1778·6
	2	1170·9	1·62		2	1797·3
	1	1187·1	1·63		1	1816·2
21	0	1203·4	1·63	18	0	1835·1
				17	11	1854·2

TABLE II. — LATITUDE.

+ 44° — 46°	+ 42° — 48°	+ 40° — 50°	+ 38° — 52°	+ 36° — 54°	+ 34° — 56°	+ 32° — 58°	+ 30° — 60°
0·0	0·0	0·0	0·0	0·0	0·0	0·1	0·1
0·0	0·0	0·0	0·0	0·1	0·1	0·1	0·2
0·0	0·1	0·1	0·1	0·2	0·2	0·2	0·3
0·0	0·1	0·1	0·2	0·3	0·3	0·4	0·4
0·0	0·1	0·2	0·2	0·3	0·4	0·5	0·6
0·0	0·1	0·2	0·3	0·4	0·5	0·6	0·7
0·1	0·2	0·3	0·4	0·5	0·6	0·7	0·8
0·1	0·2	0·3	0·4	0·6	0·7	0·9	1·0
0·1	0·2	0·4	0·5	0·7	0·8	1·0	1·1
0·1	0·3	0·4	0·6	0·8	0·9	1·1	1·2
0·1	0·3	0·5	0·7	0·9	1·0	1·2	1·4
0·1	0·4	0·5	0·7	1·0	1·2	1·4	1·6
0·1	0·4	0·6	0·8	1·0	1·2	1·5	1·8
0·1	0·4	0·6	0·8	1·1	1·3	1·6	1·9
0·1	0·5	0·7	0·9	1·2	1·4	1·7	2·0
0·2	0·5	0·7	1·0	1·3	1·6	1·9	2·2
0·2	0·5	0·8	1·1	1·4	1·7	2·0	2·3
0·2	0·5	0·8	1·1	1·5	1·8	2·1	2·4
0·2	0·6	0·9	1·2	1·6	1·9	2·2	2·6
0·2	0·6	0·9	1·3	1·7	2·0	2·4	2·8
0·2	0·6	1·0	1·3	1·7	2·1	2·5	2·9
0·2	0·7	1·1	1·4	1·8	2·2	2·6	3·1
0·2	0·7	1·1	1·5	1·9	2·3	2·7	3·2
0·2	0·7	1·2	1·6	2·0	2·4	2·9	3·4
0·2	0·7	1·2	1·6	2·1	2·5	3·0	3·5
0·3	0·8	1·3	1·7	2·2	2·6	3·1	3·6
0·3	0·8	1·3	1·8	2·3	2·7	3·2	3·7
0·3	0·8	1·4	1·9	2·4	2·9	3·4	3·9
0·3	0·9	1·4	1·9	2·5	3·0	3·5	4·0
0·3	0·9	1·5	2·0	2·5	3·1	3·6	4·1
0·3	0·9	1·5	2·0	2·6	3·2	3·7	4·2

LATIONS SUBSISTING BETWEEN SOLID AND GASEOUS ES IN THE ATMOSPHERE, AS REGARDS THEIR DIF- NT DENSITIES, AND THE PRINCIPAL CAUSES OF AT- HERIC DISTURBANCES.

§ 203.

as been already remarked that if a solid be completely
ed in a liquid, the former loses such a portion of its
as is equal to the weight of a similar volume of the fluid
). Now since our atmosphere is a ponderable fluid, it
that every body contained in it, being subjected to this
ıst lose a portion of its weight equal to that of the air it
s.

affects the accuracy of our results in determining

paper, and should contain at least 4—5 cubic fe
lower part is an aperture 10 or 12 inches in diam
the circumference of which opening two wires
other; from the point at which they intersect
is suspended, carrying a wisp of cotton saturated
of wine, which, being lighted, quickly heats and
air inclosed in the balloon.

Smaller Montgolfiers may be made to ascend
such mechanical means as will overcome their we
thread to the balloon, and carry it over a pulley
ing of a room, and hang to the other end of it a
which will exactly counterbalance the balloon.
of a spirit-lamp be held beneath the opening, th
will immediately rise.

Second Exp. The ascent of soap-bubbles and
filled with hydrogen.

To fill soap-bubbles with hydrogen, attach
containing this gas a common tobacco-pipe, o
tube, with a stop-cock; plunge the end of the
the surface of the soapy water, turn the cock, a
the bladder; bubbles will be formed which, as th
themselves from the end of the tube, will mount

The small balloons that are usually sold in th
made of turkeys' craws.—To fill them, insert a
into the neck, which must be well secured, b
thread, that there may be no escape of gas, the
the tube being connected with the discharging
gasometer (*fig.* 126.), which contains the h

then the whole weight which it is required to raise in the air $=0\cdot3927\ d^3 x + \mathrm{B}$. Let a lb. be the weight of a cubic foot of air of mean density and heat (= $\frac{1}{800}$th the weight of 1 cubic foot of water), so the weight of that mass of air which the apparatus will displace will be $0\cdot3927\ d^3 a$, whence the upward force of the balloon

$$f=0\cdot3927\,d^3 a-[0\cdot3927\,d^3 x+\mathrm{B}]$$
$$=0\cdot3927\,d^3\,[a-x]-\mathrm{B}.$$

If the air contained in a Montgolfier be heated to 212° F. it will be expanded 0·375 of its volume (the freezing point being assumed as unity), and will therefore be just that much lighter: substitute for this decimal the vulgar fraction $\frac{1}{3}$, and call the entire weight of the included air F, then from $\frac{\mathrm{F}}{3}$ deduct B, and the remainder is the force with which it will ascend. Now, as hydrogen gas, when prepared in large quantities, is never more than nine times lighter that the atmosphere, the ascending force of a balloon inflated with this gas will be $\frac{8}{9}$ F, whence the upward forces of these two kinds of balloons are as $\frac{1}{3} : \frac{8}{9} = 3 : 8$, or nearly 1 : 3, whence a balloon filled with gas may be one third the size of a Montgolfier in order that it may mount with an equal force. Gas obtained from coal is on an average half the weight of atmospheric air, so the upward force of a balloon filled with it $= \frac{1}{2}$ F, and the forces of three balloons of equal dimensions, filled in these three different modes, will be as 1 : 1½ : 2⅔. — Reason why balloons are not completely filled with gas? — Use of valve at the top of the balloon. — Use of ballast. — Mode in which the *Parachute* acts.

§ 206.

If the air at the same distance from the earth's surface were of uniform density and elasticity throughout, no motion could occur in the atmosphere; but such uniformity does not obtain at different places, nor does it remain undisturbed even at any one place. Consequently, complete repose does not prevail in the atmosphere, for, from various and frequently from small causes, the equilibrium of a fluid so easily set in motion is frequently disturbed, and the movements generated, according to the variety in the exciting cause, are transmitted with a greater or less force and velocity, and extend through a wider or more limited space. These currents of air are known under the appellations of *Winds*, *Storms*, or *Hurricanes*, according to their respective velocities; sometimes they are named from the regions of the earth in which they prevail, and at others from their peculiar characteristics.

If air thus *set in motion* meet with any resistance, it will exert

ing the air, increases its elasticity, a
lessens its density. The hotter, and s
agreeably to the laws above explained,
denser strata (just as the Montgolfier ris
sion a flowing together of cool air to fill
by the ascent of the hot air.

On this principle the following circu
plained: in heated rooms the upper strat
found to be warmer than the lower. O
room a little way, and the heated air wil
the door, whilst the cold draught sets in
current is most perceptible near the sto
which the heated and lighter air escapes,
tion the draught rushes to replace it.
breezes have in part a similar origin.
land-breeze, or wind from the islands,
whilst, during the day the sea-breeze blo
off the sea, the latter being sooner heat
hot days local currents may be observed
of the shadows cast by the clouds. A
owing the motion of ventilators in the wi
the revolution of little paper fly-wheel
balanced on an upright stem, and plac
stove.

Another cause generating a perpetual
diurnal motion of the earth, which, in co
ertia of the atmosphere, produces a motio
being in an exactly opposite direction to

§ 207.

It has been demonstrated above, that as regards the strata of a
mogeneous atmosphere, they will arrange themselves according
their specific gravities, the lighter rising through and floating
ove such as are more dense; such an arrangement, however,
es not obtain, when the atmosphere contains various vapours
d gases, not even if they are those which constitute it. On the
ntrary, it has been found that all gaseous bodies, without chemi-
lly combining, extend and mix one with another so uniformly
at gases of most unequal densities are found in juxta-position.
Even gases confined in closed vessels display this tendency to
equilibrium of mixture, if separated from the atmosphere, or
om some other gas, by a porous lamina. Thence arises a
iversal and reciprocal mixing of the gases, carried on through
e capillary tubes of the containing vessel. This process is
oken of as the *diffusion* of gases, and closely corresponds with
Endosmosis which obtains under similar circumstances be-
een fluids. (See *Exp.* 11. § 54.

It is a well-known fact that our atmosphere consists of oxygen and nitrogen. Though the latter is specifically lighter than oxygen, and does not enter into a chemical combination with it, yet at every possible elevation these two gases have been found distributed in one uniform and constant proportion.

First Exp. If carbonic-acid gas, which is about half as heavy again as common air, be put into an open vessel, in a short time a stratum of the gas will be found only at the bottom of the glass; and in no very long period this will be dissipated, and the glass will contain only the atmospheric air with the same quantity of carbonic-acid gas as the rest of the air in the room.

Second Exp. Fill a flask with any gas, close the mouth with a piece of moist bladder tied pretty firmly; if the gas be heavier than the common air, let the mouth be upwards;

---

same stream of air, which moves by the revolution of the earth from the
ator to the poles, brings to us, in its passage from the equator, the oxygen
erated there, and carries away the carbonic acid formed during our
ter.

The experiments of De Saussure have proved that the upper strata of the
contain more carbonic acid than the lower, which are in contact with
nts; and that the quantity is greater by night than by day, when it under-
decomposition.

Plants thus improve the air, by the removal of carbonic acid, and by the
ewal of oxygen, which is immediately applied to the use of man and
mals. The horizontal currents of the atmosphere bring with them as
ch as they carry away, and the interchange of air between the upper and
er strata, which their difference of temperature causes, is extremely trifling
en compared with the horizontal movements of the winds." — *Liebig's*
anic Chemistry of Agriculture and Physiology, p. 23.

Besides the currents already notice
there are likewise motions, viz. an in
portions of the atmosphere as may be
spaces that communicate with each
body of the atmosphere, and such a
only that there be a communicatio
these cases draughts will set in if
unequal densities, as the denser air
more rare.

Thus we see the origin of the drau
in chimneys, in shafts and air-passag
well as in all kinds of apparatus for w
already (§ 206.) been shown, the diffe
the air in the apartment, as compared
atmosphere, is the cause of its rarefact
various sorts of draughts or blasts
steam-engines, of air-guns, and of fi
escape of the dense air which they seve
atmosphere.

The laws of motion which th
the main analagous to those to
are subject; they are, however,
therefore more complex than the
great compressibility of aeriform
their expansibility arising from
perature.

If a gas of any density and ex

same velocity as the non-elastic fluid, whose velo-
he first second of time is $2\sqrt{gh}$ (see § 161.). Now
only to determine the altitude h. Let the density
r at the orifice be represented by d, the pressure of
it on the base of the vessel = the height b of a co-
mercury, and lastly the specific gravity of the mer-
then, according to § 156.,

$$d : q :: b : h$$

$$\therefore h = b\frac{q}{d},$$ whence is deduced the above

$$v = 2\sqrt{gb\frac{q}{d}}$$

nce d varies as the temperature of the air varies, it
that v must do so likewise; *ex. gr.*, when the ther-
stands at the freezing point, and the altitude of the
er is 30 inches = $2\frac{1}{2}$ *ft.*, $d = \frac{1}{770}$ (§ 192.), $q = 13{\cdot}59$;

h or $b\frac{q}{d} = 2{\cdot}5.\frac{13{\cdot}59}{\frac{1}{770}} = 26{,}160$ *ft.*; allowing $g =$
we obtain

$$v = 2\sqrt{16\tfrac{1}{12} . 26160} = 1296 \text{ feet.}$$

tmosphere will consequently rush into any space en-
almost void of air with the velocity just found above,
g the density and pressure to be what we have as-
The remark made concerning liquids is true also in
of elastic fluids, that the actual velocity falls short of
nd by theory. Schmidt says, when the side of the
ng vessel is thin and the aperture is small, the actual
is only 0·52 of the theoretical, but that if funnel-
tubes be inserted in the orifices, the velocity may be
0·6; this, it will be remembered, corresponds with
s observed in liquids.—After these deductions have
ade, such high velocities still remain as will clearly
for the loud report which accompanies the discharge
ms, as well as the combustion of explosive mixtures,
detonating gas and the different detonating salts. At
nent when combustion takes place, the combined
pand with prodigious force into a larger space, thus
instantaneously an almost absolute vacuum in that
hich they had previously occupied, the surrounding
es in to fill up this room with such violence as to
loud noise.

$:: \surd$

or $v : v' :: \surd$
i. e. the velocities with w
ture are in the inverse ra
In fact, the lighter any
that of hydrogen is the

It is more difficult to
flows into a space alread
the solution of the proble
expansive forces, $b-\beta$, of

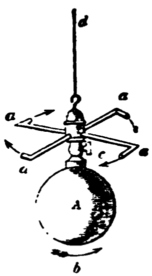
$$V = 2\sqrt{g\,(b-\beta)\,\frac{q}{d}}\;;$$

temperature, density, and c
It would be extremely diffic
retical calculation, as indeed
not be accurately solved e
branches of the mathematics.

An impulse or pressure is prod
that side of the vessel containing
aperture whence the efflux takes
to the motive power with which th
this § 165. If this force be sufficie
direction, motion ensues, which wi
continues.

The fo

Fig. 140.



turn easily about the axis of the cock. whilst the gas contained in the bladder makes its escape through them. The four orifices stand, as shown by the arrows, tangentially to the periphery of rotation. Press the gas out of the bladder, and the cross-tubes will revolve in an opposite direction to that in which the current of air escapes. In both experiments a motion is obtained similar to that in Segner's machine, § 165.

The recoil of cannons and fire-arms, the ascent of rockets, the revolution of catherine-wheels, &c. are all owing to this reaction of gases against the sides of those vessels from which they issue.

SECTION VI.

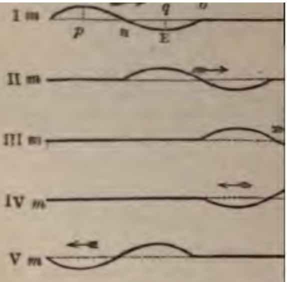
UNDULATIONS.

§ 209.

: different parts of all bodies are ordinarily held, through operation of certain internal and external forces, in a condition quilibrium. Now, if the constituent particles of a body have ı disturbed by any cause whatever (provided they have not ı carried beyond the limits within which the stability of their ilibrium is confined), they will return again to a state of se. This is effected by the particles alternately approaching position of rest and receding from it, until, after some time, ilibrium is restored. The movements thus generated are ned *undulations*, *vibrations*, or *oscillations*.

§ 210.

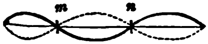
These movements are of two kinds. In the first, the unduon successively traverses the different parts of the body; those ticles which have been immediately excited by the disturbing se communicating motion to such as are next them, and so on. this case the movement of the particles is successive, so that position they assume at any particular moment during the tinuance of their motion appears to advance from one place to ther. This constitutes a *progressive undulation.*



the equilibrium of the cord, is called a *wave.* which rises above its original position, is the D the *summit* or point of greatest elevation; the level, is called the *depression* of the wav point. Again, Dp is the *height*, mn, the *le* qE the *depth*, no the *length* of the *depressio* *of the entire wave.*

Such a wave does not continue stationary, 141. II. represents, towards the other extr on arriving at which, *fig.* 141. III., an inverte is produced; and the wave returns, *fig.* 141. from which it started; its position being only the relative situation of its elevation versed; this movement may be repeated seve mpinging on each other, when this form will pass into its conerse, and *vice versâ*, as is represented in *fig*. 142. by the continuous and dotted lines. The points *m* and *n*, which bound an elevation and a depression, continuing at rest during the undulations, are termed *Nodal Points.*

Fig. 142.



§ 211.

Bodies of all three forms of aggregation admit of these vibraions being induced in them; the movements, however, are modiied both by the form of the body itself, and by the nature of the xciting force. Such forces are either purely internal, as elastiity, which is the principal agent in solid and aeriform bodies; r external, as gravity, which causes this kind of motion in luids.

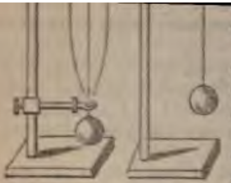
An acquaintance with the laws of undulations is on many ccounts of great importance in the pursuit of physical science. ur perception of sounds by the organs of hearing depends enirely on the vibrations of sonorous bodies communicating an unlulatory motion to the air by which we are surrounded. The henomena of light and radiant heat may also be most satisfacorily accounted for on the hypothesis that there exists a certain mponderable medium which is put into a state of undulation; easoning from analogy, too, it seems probable that other effects hich are commonly attributed to the motions of different imonderable bodies will admit of a similar explanation. We shall ow proceed with greater exactness to consider the most imortant laws by which these movements are regulated in solid, uid, and aeriform bodies.

I. UNDULATIONS OF SOLID BODIES.

§ 212.

Such solids as possess a sufficient degree of elasticity can alone e made to vibrate for any length of time. Many bodies of this ass, as cords and membranes, acquire the requisite elastic force y means of tension; in others it is an innate property of their ass, as in rods and plates of metal, glass, and even wood.

Bodies of a *lineal* form, as, *ex. gr.*, tense strings and fine wires re susceptible of three distinct kinds of vibrations, that is to say, ch bodies may incline from a position of rest on both sides in e direction of their length, or they may alternately extend and ontract, or, lastly, their particles may move about the axis, alterately advancing and receding. The first and most common ovement is called a *transverse* vibration, the second a *longitudinal*, d the last a vibration *of torsion*.



weight by w
tight.
The *transv*
produced by s
the wire by me
clamp, as repre
then pulling th
dle from its p
suddenly lettin

The *longitudinal* vibrations may be ex
then letting go the weight by which t
tight.

The *rotatory* vibrations are induced b
by means of the weight attached to it, an
weight to fall suddenly.

Bodies having a large *plane* surface, such
tense membranes, are susceptible of transve
whilst bodies of pretty nearly equal dimensio
may be made to vibrate in each of the modes

§ 213.

In all these movements elasticity is the forc
in the case of a pendulum, tends to restore
vibrating body to their former state of equilib

The oscillations of a pendulum, as to exter
nearly resemble the transverse vibrations of a
seen in the apparatus described above, or ev
wire or catgut. Let any such body, *a f b*, *f*

ntly it cannot retain this position, but moves on with a con-ntly decreasing velocity till it arrives at *adb*, where its velocity ul. The force of tension again brings the cord back to *afb*; recedes again till, as has been just shown, its velocity is anni-ated, and so on.—One complete movement from *acb* to *adb*, d back to *acb*, is termed an *oscillation* or *vibration*, and the ne occupied in performing it is called *the time of an oscil-ion.*

The principal laws which have been deduced from both theory d experiment respecting these vibrations of tense bodies are the llowing:—

1) The vibrations are perfectly *isochronous*, or occupy each an ual duration of time; in this point resembling the oscillations the pendulum.

2) The number of vibrations in equal successive portions of me increases, or, in other words, the vibrations become more pid (a), if the force of tension, or the body's elasticity, be in-reased, and that in the ratio of the square root of the force (b); the string be shorter, in which case the number of vibrations ill be inversely as the lengths; and (c) inversely as the diameter f the cord is greater.

Let S, *s*, represent the elastic force of two strings; L, *l*, their lengths; D, *d*, their diameters; and N, *n*, the number of vibrations in any particular unit of time; then the above laws may be generally expressed in the subjoined formulæ:

$$N : n = \frac{\sqrt{S}}{LD} : \frac{\sqrt{s}}{lD}$$

and if the times of an oscillation be represented by T and *t*, the times being inversely as the number of oscillations, we have

$$T : t = \frac{\sqrt{s}}{ld} : \frac{\sqrt{S}}{LD}$$

§ 214.

If a body in a state of tension acquire a stationary undulation, uch that it becomes divided into several vibrating parts, then hese parts will all be of equal size, they shall all vibrate with qual velocities, but those which are contiguous in opposite irections, and the number of the vibrations will be inversely as he size of the parts.

Exp. An undulation of this kind may be very plainly shown by means of the tense wire (*fig.* 144.), thus: Press on the uppermost quarter of the wire with two fingers of the left hand, whilst with two fingers of the right hand you press on the lowest quarter, draw the wire thus held in

at one or both ends. Theory and experimen
equal times the number of complete vibration
form rod is inversely as the squares of the len
parts.

> If, for example, a steel wire fastened at
> vibrations in a second, with half the le
> four times as many, or eight; with on
> sixteen times as many, or thirty-two vibr
> Supposing the rod to be perfectly unif
> calculate how many vibrations it would
> ticular length.

The particles of a rod thus set in motion d
do not always lie in the same plane, but return
lines. This is clearly seen if a polished knob
free extremity of the rod. — On this depend
dophon.

> *Exp.* Fasten some fine steel wires —
> or twelve inches long will do very well
> end into a board; on the other end fix o
> metal knobs. If these wires be made t
> speck on each of the knobs will be seen
> curves.

Elastic rods are equally capable with strin
by stationary undulations into several vibratin
the detached end of the wire is half the lengt
between two nodal points, but it vibrates with
the number of vibrations increases uniformly
parts into which the rod divides itself. *Fig.*

ibrating portions, the contiguous ones invariably moving in ry directions. Conceive such a plane to be intersected by a second plane at right angles to the nodal lines; then the intersecting plane will form an unda with stationary waves, just like a rod vibrating with both its extremities free. See *fig.* 146. The bounding areas are always half the size of the interior. The number of vibrations in- s with that of the nodal lines.

Fig. 146.

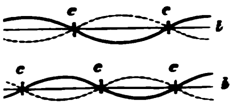
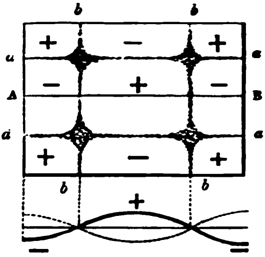


Fig. 147. will render the above easy to be understood. *a a*, *b b* are the nodal lines, the areas bounded by them and marked + are elevated, those marked — are depressed. The figure beneath shows the undulation, supposing the plane to be intercepted by another plane at right angles to it in A B.

Fig. 147.



How the existence of these nodal lines may be rendered visible will e shown presently in treating of sound.

II. UNDULATIONS OF NON-ELASTIC FLUIDS.

§ 217.

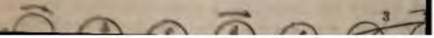
a depression be made at any point in the surface of a fluid state of rest, either by dropping a solid into the fluid or mmersing and then withdrawing the solid, an *undulation* be produced. Around the point of depression there first a circular elevation above the level of the water when *in brio*, and immediately beyond this a corresponding depres- this constitutes a *circular undulation.* The wave is pro- ve, forming continually enlarging concentric circles further urther from the point at which it originated. A succession ves will arise and traverse the same course from the place the first arose, and this process will continue so long as articles of the fluid are in motion. Thus the movement of ate elevations *and depressions* in concentric circles goes on

and by its length the length of both the
portions.

In a movement of this kind the fluid appears
mass advanced progressively from the point of e
is, however, by no means really the case, but eac
fluid describes a vertical circle about the spot
happen to be, in the direction in which the wav
the particle returns again to its former position in
one half being above and the other half below
fluid. Every particle of the fluid thus put in m
imparts a similar motion to its contiguous partic
the next, and so the movement is propagated.
particle must therefore begin to move at a poi
than the preceding; and consequently at any pa
the movement of each individual particle in its a
will differ from that of the others in height, hen
the fluid derives its undulating form. The fl
occupies the same place, and the moving form c
is merely the figure of the curve in which the in
of the fluid lie. This is obvious if you obse
floating on the waves of the sea is almost statio
just rising and falling with the elevations and d
water.

Fig. 148. is intended to illustrate this r
sake of simplicity, we will consider only eig

Fig. 148.

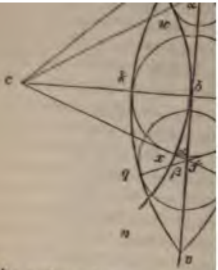


stant. Assume, now, that each particle of the fluid begins its movement in the direction of the arrows $\frac{1}{8}$th of a revolution later than its neighbour next it on the left hand, then, at the instant when *a* has completed one entire revolution, the second will be $\frac{1}{8}$th of a revolution behind it, viz. at 7; the third, $\frac{2}{8}$ths behind it, viz. at 6; and the fourth, fifth, sixth, seventh, and eighth, at the points 5, 4, 3, 2, 1, respectively; whilst the ninth particle is but just beginning to move. Connect the points *a*, 7, 6, 5, 4, 3, 2, 1, *m*, and the line will represent the form of the fluid's surface at that precise moment of its undulation. From this it will be perceived at once that the radius of the circle, described by each of these particles, is equal to the height of the elevated or the depth of the depressed portion of the wave, and also that each wave advances a distance equal to its own length in the same time as each particle accomplishes its revolution. Again, those particles which lie below the surface of the wave have their equilibrium disturbed simultaneously with the superficial particles, so that, to a certain depth at least, the successive strata assume a position parallel to that taken by the surface. The brothers Weber in their experiments found that in water this sympathy extended to a depth below the surface equal to the altitudes of 350 waves.

§ 218.

If progressive waves impinge on solid objects which check their further advance, a backward movement of the waves will ensue. This *reflexion of the waves* is owing, not to the elasticity of the particles of the fluid, but is occasioned by the action of gravity; it obeys precisely the laws which regulate the impact of elastic bodies, whence it follows that *all the points in a wave will be reflected from the surface of a solid under the same angle at which they struck it.*

Lines drawn from the point at which the impulse is communicated to a circular wave to different points in the circumference of the circle, will express the directions in which these points are respectively advancing. Such radiating lines are appropriately termed *rays of undulation.* Those drawn from one centre of impulsion are diverging, those drawn from two such central points at an infinite distance asunder are parallel. Rays moving from heir centre of impulsion against any solid body, as, *ex. gr.*, *x f*, *c b*, *c w d*, *fig.* 149., are said to be *incident;* those which, fter impact, recoil from the resisting object, are *reflected* rays, nd their direction is determined by the law given above; that s to say, *the angle of incidence* which the ray makes with a *perendicular*, drawn through the point of impact, is equal to the



u v, from *d*, the point of impact, draw
the angle *a* or *c d s* is equal to the
two angles are on opposite sides of
it follows that parallel rays falling
parallel when reflected from it, diver
verging converging, and such as are
on their own track.

When the diverging rays of a cir
plane surface, their reflexion ensues ex
originated at a point *a*, *fig*. 149., as far
ance as the centre *c* of the original wav
the reflected wave forms a circle, *v k u*.

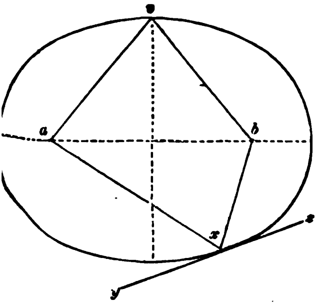
If a circular wave advance prog
surface, it is evident that all its
simultaneously on the solid. The
wave *m b n*,

centres whence they start are more or less remote from the perpendicular $c\,k$. Were it not for the interposition of the solid obstacle $u\,z$, the wave $u\,i\,s$ would have arrived at $u\,e\,z\,p\,r$ in the time which elapsed between the impact of the point k, and that of point u at u, whence the rays produced $u\,u$, $u\,e$, $b\,z$, $x\,p$, are all equal. But during this time the ray reflected from i has traversed the distance $bk = bz$; that from f the distance $fq = fp$; and that from d, $do = de$. Now since, as may be easily proved geometrically, all the reflected rays if produced, as $d\,a$, $i\,a$, $f\,a$, will meet in a, a point as far on the one side of $u\,r$ as the original centre of impulsion c was on the other side, it is evident that the lines $a\,f$ and $c\,f$, $a\,d$ and $c\,d$, and also $ab + bk$ and $cb + bz$, or $a\,k$ and $c\,z$, $af + fq$ and $cf + fp$, or $a\,q$ and $c\,p$, $ad + do$ and $cd + de$, or $a\,o$ and $c\,e$, are equal to each other. But $c\,e$, $c\,z$, $c\,p$ are radii of the arc $u\,e\,z\,p$, whence also $a\,o$, $a\,k$, $a\,q$ are radii of a circular wave, which we can imagine to have sprung from a as a centre, and whose arc $u\,o\,k\,q\,r$ results as an entire reflected wave from the many small circles which originate at all the points where the different parts of the original circular wave successively impinge on the solid.

§ 219.

If the solid from which the wave is reflected have not a plane but a curved surface, then the rays will be thrown off from such a surface in directions answering to the curves, and the path of the returning wave may be deduced from the laws laid down in the preceding section. On account of the results arising from these reflected waves, as they are met with in the case of sound, light, and heat, the circle, the ellipse, and the parabola possess peculiar interest.

Fig. 150.

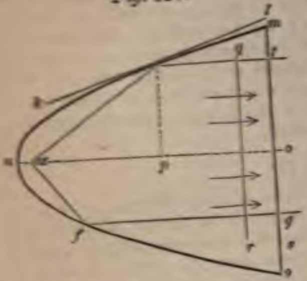


All rays of undulation proceeding from the centre of a circular vessel containing a fluid will impinge perpendicularly, and at the same instant on the boundary; from it they will be reflected, and arrive again together at the centre.

If an undulation be excited at one focus, a, *fig.* 50., of an ellipse, all the rays diverging from this point will be so

tical form (the vessel may be made of wood,
board) so as completely to cover the bott
few drops of the metal fall through a fine gl
fluid surface at the focus *a*, *fig.* 154., and c
dulations will be excited at *b*.

Fig. 151.



If the surface have a parabolic form, *fig.* 151.,
travel from its centre *a*, then the rays imping
boundary
in such a
will mov
parallel t
the parab
in the fig
ing so as
wave, th
right ar
ordinate
the figur
if there
waves, a
a direct
to the a
bola, then will all the rays of such a wave b
interior of the curve so as to impinge sim
focus *a*.

Hence it follows, that if an impulse be ex
fig. 152., of one parabola, and the waves of

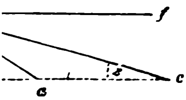
ll meet together at the focus *b* of this second para-

motion of the waves described above is owing to these perties of the parabola,— that, at any point *c* of the he angle *ack* will be equal to the angle *tcl*, if *tc* be to the axis; and secondly that the sum of the lines *ac* is equal to that of *af* and *fg*.

d *Exp.* These properties in the movement of undu- propagated in a parabolic surface, may be experi- ly shown, by filling a vessel of the required form with y, and proceeding as in the preceding experiment. ust be taken that the curves have a common axis, and e sides fit when put together.

ected from a very small circular arc will in their direc- imate closely to those reflected from a parabolic boundary. The focus of such an arc lies at the distance of half the radius from the centre of the circle.

Fig. 153.



Let *mbn*, *fig.* 153., be an arc of a circle, *bc* its radius, and *a* a point about half-way between *b* and *c*, then $ca=ab$, and if the arc *bg* be assumed very small, then *ab* may be considered $=ag$; *cag* will therefore be an equilateral triangle, and angle *y* will be = angle *z*. *gf* parallel to *bc*, then angle $x=$ angle *z*, and con- tly angle $x=$ angle *y*, and angle $\alpha=$ angle β, as in the la.

§ 220.

ulse be communicated at two points in the surface of the waves thus generated will intercept each other, laces where this occurs there will be a change in the waves. If two elevations meet in exactly opposite elevation of double the height will be produced; if ions meet, a depression of double depth will be pro- f an elevation and a depression meet, the surface of remain undisturbed, each counteracting the other. annihilation is termed the *interference* of waves. dulations have thus crossed each other's path, they r progress unaffected by this interception.

According to accurate experiments perfo and Sturm (1826) on the Lake of Geneva, in water vibrations are transmitted with French metres, or 4708 English feet, in a

The rapidity with which vibrations m through other fluids cannot be determined ment, but may be deduced with tolerable respective elasticities.

§ 224.

The undulations of incompressible fluids on o treme importance, especially those of water, a undulations of the sea. Did not water possess of the mobility of its particles among each oth being thus set in motion, the ocean would soon by the mass of organised matter it contains; it served by its incessant undulations. The cause chiefly to maintain this state of constant moven tractions of the sun and moon, which produce t the tides; the rotation of the earth upon its axi the constant easterly current; and, lastly, the win the most violent disturbance of the waves, an from its very depths. By means of the mec ciated with these violent movements in so lar as the ocean, effects are produced which have b are still bringing about, important changes in globe.

As water was the liquid whose phenomena most demanded our notice, so in bodies of the class now under consideration the atmospheric air is that which may serve as a type of all other gases, and the results found to obtain from its movements may be held true of theirs.

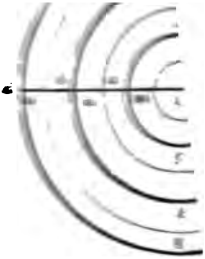
§ 226.

If a vibration be imparted to the air at any point whatever, it will be communicated to the surrounding particles, which will recede, in consequence of the facility with which they move among each other, with equal velocity in all directions, driving before them all those particles which lie in their path. Each of these, because of its inertia (§ 27.), opposes a certain resistance to this movement, and the air, by virtue of its compressibility, becomes condensed; consequently, the movement of the particle originally excited lasts only until overcome by this resistance. Hence there is formed about the point of impulse a *sphere of air*, which attains its maximum density at its boundary, at the very instant its further expansion ceases. The reaction of the condensed air then opposes the expansive tendency, the sphere contracts, and the particles resume their former positions. During this contraction of the particles originally set in motion, the undulation is imparted from one portion of the atmosphere to another at continually increasing distances from the original centre; thus, at the moment when the particles on which the impulse was first impressed, have recovered their former places, the undulation is transmitted to an equal distance in all directions. The radius of this hollow sphere of air, or the distance the undulation had traversed when the first particles resumed a position of rest, is called the *length of a wave*, and the entire sphere compressed within these limits constitutes *a wave*.

From the above explanation it follows, that the time of a particle's vibration, or the time which elapses whilst it attains its greatest density at its exterior, and thence returns to a state of rest, is exactly equal to the time in which the motion is propagated through the entire length of a wave, *i. e.* through the radius of the spherical cavity.

If the cause which excited the undulation continues to operate, there will arise a second, third, &c. wave within the first, and concentric with it. This radial propagation of the undulations can take place with equal velocity only when the atmosphere is equally dense and equally elastic in all directions. If this is not the case, the vibrations do not succeed each other with equal velocities in all directions, and consequently such a wave cannot have a spherical form.

Let *c*, *fig.* 157., be the point of impulse of the vibrations



fore the particle m had arrived a
the length of a wave. The same l
the points a, e, and d, and the dis
ceive the sphere of air to be inters
through the point of impulse c, the
dlpg will be the sections of success

§ 227.

If waves of air proceeding from t
together, appearances present themselve
those already described in the case of
220. and 222.; the waves intersect an
freely. At those points of
both the

and they are supposed to advance in the direction ac. Let the ordinates nm and op represent the velocity with which a particle n and a particle o vibrate at the same moment; in other words, let it represent the *intensity of the vibration*, then the line $amfpb$ will be the *curve of the intensity* of the first wave that proceeded from a; and if similar significations be attached to the ordinates, qs, vu drawn to the line bc, which marks the further progress of the wave, we shall have $bsguh$ as the curve of the intensity or velocity of the second wave. If now another undulation arise, in the same direction, at b, the beginning of the second wave, having a velocity qr at q, a velocity vw at v, then *the force of both systems is increased*, and the particle at q acquires a velocity $qt = qs + qr$; that at v a velocity $vx = vu + vw$; and the curve of intensity generated by their combined operation is the line $btgxh$. But if the points of impulse a and b be only the *length of half a wave* apart, as represented in *fig*. 159., then the particle at q acquires from the wave that starts from a the velocity qs; the particle at v the velocity vu; and from the wave at b the former particle receives the velocity qr, and the latter the velocity vw; but as these directions are exactly opposite the one to the other, the intensity of the vibration at q is $qs - qr = qt$; at v, $vu - vw = ux$; and $btgxhc$ is the curve of intensity formed in this case. Thus arranged, the systems

Fig. 158.

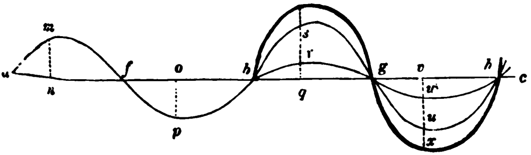
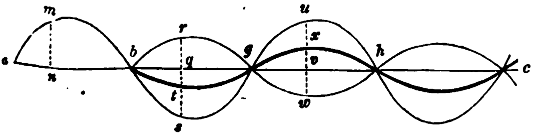


Fig. 159.



indeed that its
but they may be
been greatly dim.

Our organs of heari
vibrations. To the pro
is sonorous body. one th
or rather the vibrations
this class are called *sonif*

Any body may become
soniferous medium to vibr
Consequently we hear with
wings, the report of a gun.
bodies are best suited to con
directions throughout their
brations imparted to them
density and elasticity are indis
as wool, hair, feathers, and the
of conducting sound.

§

If a sound be produced whose
dividual sounds composing it
human ear can not only recognise
tinguish one from another:
words to mark the
rattle.

e bodies then can alone produce musical sounds. Elasticity fact the unceasing motive power which, like gravity in the of the pendulum, sustains the permanence of the undulation. me solid bodies possess the requisite elasticity by virtue of nternal arrangement of their molecules; to this class belong al metals, steel especially; then glass, and even wood; to rs we impart the necessary degree of elasticity by means of on, as, *ex. gr.*, to metallic wires, catgut, and animal membes. To excite such undulations in aeriform bodies, we conthem in tubes. Recently even liquids have been made to musical sounds.

§ 234.

nese vibrations can be excited only in those bodies whose di- sions of length or breadth exceed their thickness. For the uction of musical notes we commonly use either rectilinear urvilinear bodies, as tense cords, metal and glass rods, or co- s of air inclosed in cylindrical or other tubes; or else bodies nting a large surface, either plane or curved, such as mem- es strained tight, plates of glass or metal, and bells.

neal bodies may consequently perform either *transverse*, *lon- inal*, or *torsion vibrations* (§ 212.), but bodies which have an nded superficies can vibrate only in the first of these modes. n, a body may vibrate as a whole throughout its entire ex- or it may be divided into a number of aliquot parts, those h are conterminous moving in opposite directions; in other ls, a stationary undulation may be induced: where these s meet, the body will be at rest. Thus in cords, rods, and ar bodies there will be *nodal points*, and in bodies with ex- ed surfaces there will be *nodal lines*.

hese musical undulations may be induced by various means itable bodies; for instance, by friction, by impulse, or by a . The actual existence of such vibrations as have been de- ed may be rendered visible by placing small light bodies in act with the excited body, when they will be seen to acquire nilar movement. If you stop the vibrations of a body that ving out musical sounds, the sound will cease at once, and so the vibrations of the attached bodies.

First Exp. Attach a small ball by a string to a bell, ring the latter, and the ball will be seen to vibrate.

Second Exp. The string of any musical instrument, if it be made to give out musical sounds, will by its vibrations jerk off small pieces of paper that may be laid on it.

Third Exp. Strike a tuning-fork, and touch the surface of a mass of quicksilver with the tip of the fork, and the fluid will begin to undulate.

[illegible]

The different [illegible]

[illegible] in quality [illegible]

[illegible] quantity depends on the [illegible] then shorten it, its excursions will be more rapid (§ 213.), and accordingly the note produced will be higher.

It is still more difficult to ap- ciate the *quality* of a sound, though the faculty of distinguish- sounds is one in constant exercise: when notes equal in ensity in height or depth are produced by different bodies, we able readily to distinguish one from another, and can assign em to the bodies from which they respectively proceed. No isfactory explanation has yet been given of the emotion by ich, for instance, we distinguish the human voice from that of ird, or from the tones of an instrument.

§ 236.

The capacity of the human ear for perceiving the vibrations of dies is confined within certain limits. It has been determined perimentally, that the lowest note we can appreciate is that oduced by a body's performing 32 half-vibrations, or 16 im- ulses, in one second of time, and the highest when it performs bout 16,000 in the same space of time. A fine ear is, however, ble to recognise, as a distinct sound, a kind of hissing noise made y a body performing 48,000 half-vibrations, or 24,000 pulses, in a second.

Chladni adopted the following simple method for determining the number of vibrations made by a body emitting musical sounds.

Exp. A strong uniform strip of steel, several feet in length, about six lines in width and one in thickness, is to be securely fixed at one extremity in a vice, in such a manner that when the free end is set in motion it shall make 120 half-vibrations, or 60 pulses, in a minute; it will then make 2 of the former, or 1 of the latter, in a second. Fasten it a second time in the vice, so that the free end shall be only half as long as at first, then the number of half-vibrations in a second will be $4 \cdot 2 = 8$ (§ 215.). Halve this again, so that one-fourth of the original length shall vibrate, and we shall have for the number $4 \cdot 8 = 32$, and the half-vibrations will now constitute a note

---

§ 236. "The maximum and minimum of the intervals of successive pulses still appreciable by the ear as determinate sounds, have also been determined by M. Savart, more satisfactorily and more accurately than had previously been done. If their intensity is sufficiently great, sounds are still audible which result from the succession of 48,000 half-vibrations, or 24,000 impulses, in a second, and this, probably, is not the extreme limit in acuteness of sounds perceptible by the ear. Again, the sound resulting from 32 half-vibrations, or 16 impulses, in a second, is not, as has been supposed, the lowest appreciable note: on the contrary, M. Savart has succeeded in rendering sounds audible which were produced by only 14 or 18 half-vibrations, or 7 or 8 impulses, in a second: and sounds still deeper might probably be heard if the individual pulses could be sufficiently *prolonged*." — *Müller's Physiology*, p. 1229.

of air. When the numb
the lowest note is extin
to about 16,000 per sec
a mere whistle.

Besides the physical effect
sense of hearing, they also exer
character; for we experience a
on hearing several notes either
In the former case the notes are
they are *discordant*. The comb
a *chord*, an agreeable succession
cession of chords constitutes *harm*
Music is the varied application
sounds; it forms a language whic
to all mankind.

§ 23

On closely investigating the rea
sounds were consonant and other
this depended on the greater or
between the notes in regard to th
Such a relation expressed in the
interval.

The simplest or most consonant i
in which the higher note ma

ollowing table, that which is most worthy of notice has been rought together at one view.

Notes.	Fund. Note.	Second.	Third.	Fourth.	Fifth.	Sixth.	Seventh.	Octave.
	C	D	E	F	G	A	B	c
Number of vibrations of the upper note - - -		9	5	4	3	5	15	2
Number of vibrations of the fundamental note - -	1	8	4	3	2	3	8	1

There are three of these notes which together form the most agreeable combination to the ear, they are C, E, and G; this chord of three notes is called a *triad*. In this instance, again, it appears that the effectiveness of the combination is owing to the simplicity of the vibrations, for in the time that the fundamental note C performs 4 vibrations, its third E makes 5, and its fifth G 6. This combination of the fundamental note C with the major third E and the fifth G is called the *perfect major chord*.

Without entering fully into detail on this part of Acoustics, we may add, by way of supplement, a few remarks on the *chromatic scale*, and also explain what is meant by *even temperament*.

By glancing at the table of the diatonic scale, it will be seen that the seven intervals, though nearly equal, do not exactly correspond; consequently it is not possible to keep up the harmony of the notes if any other than C be selected as the fundamental note. To enable us, then, to select some other note than C, and do away with the inequality subsisting between the 7 intervals of the diatonic scale, *semi-tones* have been introduced between the *entire tones*, *i. e.* between the fundamental note and the second, the second and third, the fourth and fifth, the fifth and sixth, the sixth and seventh, and the octave is thus made to consist of 8 entire, and 6 semi-tones. This scale, which contains 12 intervals, is called the *chromatic scale.* But even in it the differences between the intervals are not perfectly equalised, though in practical music it is assumed that they are. To make the 12 intervals of every octave fall exactly, the difference must be so distributed among all the semi-tones of the octave, that when sounded they do not bear an exact ratio to any fundamental note whatever, but the deviation is so small that it is not perceptible. When an instrument has been tuned in this manner, it is said to have an *even temperament.*

The equal interval obtained between all the notes when

anding based on
that the harmony of n
coincidence of simple r

C. *Musical Vibrations of*

§

The phenomena presented
in their vibrations, which subj
notice, may be most easily ill
tions of tense cords. The appar
called a *Monochord* or *Sonometer*.

In its most simple constru
a single string of wire or catg
pins across two wooden brid
pretty strong board; that part
is graduated, so that the latt
vibrate in any required number

As the number of vibrations mad
i. e. as the note it gives forth become
the cord is shortened, and as the heigh
the length of the cord (§ 213.), it follo
scale may be obtained from a *single*
half of any cord will give the octave, $\frac{2}{3}$r
the fourth, &c. of the fundam
cord.

octave, by straining a string with a power four times greater than the original power.

Second Exp. The truth of these remarks can be tested if the string be strained by means of weights, such as are used in Fischer's and Weber's monochords.

Lastly, the strength of the string and the material of which it is made materially affect the height of the notes, which will be higher in proportion to the strength of the string (§ 211.), and the elasticity and density of its material. Thus with equal tension, steel-wires yield a higher note than brass, and these again than catgut.

Third Exp. These facts may also be proved by means of a monochord furnished with weights to strain the string.

§ 240.

A string vibrating transversely may be divided into many vibrating portions; in other words, it may assume the form of a stationary undulation. This movement may be communicated to a string by touching it at any aliquot part of its length, and then drawing the bow of a violin across the part thus marked off. The whole cord will instantly divide itself into equal portions, and wherever two are conterminous there will be a nodal point. The greater the number of such parts into which the string is distributed, the higher the note, and the numbers of vibrations will be inversely as the dimensions of the individual parts. (§ 213.)

Exp. This arrangement will present itself as you perform the fourth experiment described in § 234. — The height of the notes will be found to increase as the number of vibrating parts: half the string will yield the first octave, a quarter of it the second octave, an eighth the third, and so on, of the fundamental note — Notes of a flageolet, Æolian harp.

§ 241.

Bars of a cylindrical or prismatic form are susceptible of transverse sonorous vibrations equally with cords. But as such bodies are elastic in all directions, and consequently their elastic force acts not lengthwise only, their vibrations do not obey the same laws, nor are they excited in the same manner as those of strings.

In similar bars the height of the note is directly as the thickness and inversely as the square of the length. — *Chladni's Sonometer*, § 236. The degree of the body's elasticity greatly influences the character of the note; thus steel gives a higher note than brass.

which an ex
position depends on th
and excited, as one of these
the point at which the plane is
the vibratory motion at the ot
peculiar figures, called, after t
Figures.

To make these figures vi
nent, adopt the plan des
§ 234.; they may also be s
be poured on the plate, say,
on it. *Wheatstone* was the fi
last-named mode, still more
were observable.

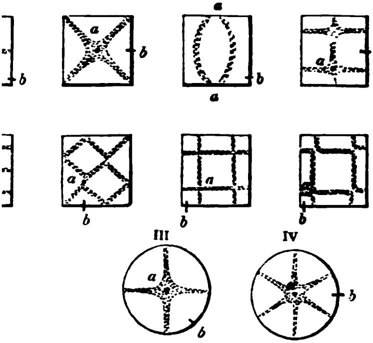
These sonorous figures are comp
sometimes of curves either parallel t
The shape of the plane greatly affect
arranged, according as it may be a s
a circle, an ellipse, or some other figu
well-defined figure is produced only w
clear note.

By experiments made on such plates
detected by Chladni:—

1. Any particular note will always
with the same plate; but a small chang
in the figure by slightly changing the pl
held without causing any difference in th
changed, the existing figure
arranges itself.

First Exp. If the plates, *fig.* 163., be strewed with fine d, and held at the point *a*, whilst the bow be made to pass *b*, the figures there depicted will in each case be produced.

Fig. 163.



riking effect is obtained by making the same figure on plates of equal size and similar form, and then so arrang- m as to make one figure on a larger scale. The figure roduced will be both a *compound* and *connected* one, and may not unfrequently be met with on a large plate.

Second Exp. If a large square be formed out of four

Fig. 164.

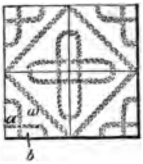
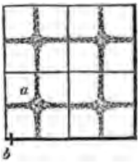


Fig. 165.



uares, bearing the figures (*fig.* 163.) I. and II., we shall have *s.* 164. and 165.

If a large square plate, *figs.* 164, 165., be held at *a*, touched *a′*, and a bow be drawn across at *b*, similar compound ures will be generated.

bals, the Chinese *Tam-tam*, or *Gong*, are practical appli- of sonorous plates.

[illegible]

[illegible]

[illegible]

elevating the fla

[illegible]

[illegible]

by the combustion of

[illegible]

Hydrogen in the

phuric acid on z

lete. The flask mu

posed the hydroge

air. The close

which a glass tube,

from [illegible] of a

is tapered off at *b*, w

ing the gas is to

issues from *b*. Ov

[illegible]

F. *Of the Organs of Voice.*

§ 250.

The *organs of voice* in man and in the inferior animals closely resemble those instruments in which the air is rendered sonorous by means of an elastic mouth-piece.

The human organs of voice are the *trachea*, or windpipe, the *larynx*, and the *cavity of the mouth.* The lungs and chest act like the bag of a bagpipe, the trachea answers to the pipe; at the head of the trachea is the larynx, which is the principal organ in producing the voice. The larynx is a widening of the upper part of the trachea, over the opening to which two semicircular membranes are stretched, so as to contract the trachea into a small cleft called the *glottis*, which is narrowed or widened at will, according as these membranes are exerted or relaxed. Besides these organs, especially formed for producing the voice, we have the roof of the mouth, the pliant lips, the ready tongue, and the nose, by the aid of which we variously modulate the sounds we utter.

§ 251.

The organs just named are thus used: in expiration the air passes from the lungs through the trachea and larynx into the mouth. If the glottis be open, the air passes without obstruction, and its motion is inaudible; if, on the contrary, the membranes of the larynx and glottis be contracted so as to narrow the aperture, the air is driven through forcibly, and these membranes impart their vibrations to the current of air. In this manner an *inarticulate sound* is produced; and it is plain that the mode in which it is generated is closely analogous to that in which musical notes are excited in clarionets and other similar instruments. (§ 246. 4.). Different impediments are offered, at the pleasure of the speaker, to these pulsations of the air, which he checks with the tongue, lips, and teeth, thus presenting very differently formed apertures for the escape of the air, by which means the sound is modified so as to make that variety of tones called *articulate sounds.*

The air which produces the voice has two passages in the mouth, one at the head of the trachea, which the tongue can close more or less exactly, and the outer one, which is opened and closed by the lips. By opening or closing one or both of these passages we form those sounds called by grammarians *vowels;* the *consonants* are made by impeding the *escape of the breath* by means of the tongue, lips, or

and perhaps also
breath is forced through it
the voice.

The compass of the
octaves. The deepest
vibrations, and the hig
voice 375, and the highe
pears that the same voic
octaves of complete notes.

§

The voices of the lower anim
all brutes, however, are not a
which have lungs are endowed
mammalia, birds, and amphibian

G. *Resonan*

§ 2

The vibrations of sonorous bo
which they come in contact. It
they readily acquire the same vi
the sound possesses, and by th
resonance as it is called, they stre
tic bodies are most susceptible o
inelastic substances, on the
stifle sound by d
instr

II. TRANSMISSION OF SOUND.

A. *Transmission of Sound through Atmospheric Air, through Water, and through solid Bodies.*

§ 255.

It has been already shown in §§ 231. and 232. that for us to be able to perceive a sound a *conductor* is required that will connect our organs of hearing with the sonorous body; in the same part of this work the characteristics of such a conductor were mentioned.

The most general conductor of sound is our atmosphere. It is in contact with our organs of hearing, and, being co-extensive with our earth, it necessarily touches every sonorous body upon it. Being an elastic fluid, it is peculiarly adapted to transmit the pulsations of sonorous bodies by its own undulatory motion in all directions with equal velocity. Every vibration of the sonorous body produces a progressive wave in the air, which moves in a direction perpendicular to the surface of such body. These undulations are called *waves of sound*, and every right line, perpendicular to their surface or to that of the sonorous body, is called a *ray of sound*. It generally shows the direction whence the sound emanates; for which reason we always imagine the sonorous body to be in that direction in which our ear is affected by the rays of sound.

From the explanation just given it follows, that the motion of the air in the transmission of sound is distinct from its sonorous motions. In the former case it merely extends the motions generated by some other body by its progressive waves, in the latter it assumes a stationary undulation.

§ 256.

When waves of sound are excited simultaneously in different places, each advances, according to the laws of undulatory motion (§ 220.), independently of the other. Where they meet, they cross each other's path, and after this intersection each pursues its course unaltered. From this circumstance we may comprehend how several sounds and notes may be heard at once. It is only at their points of intersection that they affect each other, by adding to or diminishing their force, or even by neutralizing each other, when *interference* arises.

Exp. Hold a tuning-fork in a state of vibration, so near to the ear that its tone can be easily distinguished; if its handle be turned round with moderate quickness, it will

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round over the
The waves of sound
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The velocity with which the §
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It has been found, as the result
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[illegible] 1089·75 English feet,
[illegible] the progress of sou
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e distance in yards nearly. It is supposed that the pulse beats 72 times in a minute.

b. The velocity increases with every degree of Fahrenheit's ermometer above freezing point about 1·1 foot. At a mean emperature of 60°, the air being in an average state of moisture and perfectly at rest, we may reckon that sound moves 1130 feet in a second.

These results accord with what has been noticed respecting the vibrations made by columns of air in tubes, such as organ-pipes; a column of air intended to make the deepest note in an organ, i. e. to make 32 vibrations in 1 second, will therefore require a pipe rather more than 32 feet in length.

§ 258.

The velocity with which a wave of sound advances in water, ccording to experiment (a), is about 4 times greater than its elocity in air. It amounts to 4706 feet in a second. This is lso pretty nearly its rate on ice.

The velocity of sound in solid bodies has scarcely been investigated, as direct experiments can rarely be performed on a sufficiently extended scale. It is generally believed that solid bodies transmit sound most quickly, but with by no means equal velocity. (b)

a. These experiments were made by Colladon and Sturm in the Lake of Geneva. (Compare § 223.)

b. Biot found, by direct experiment, the velocity of sound in cast-iron, using pipes 3000 feet in length, made for the purpose of conveying water into Paris; he informs us that it is 10½ times greater than in air. Chladni has inferred that sound travels in tin 7½, in copper 12, in iron 17(?), in glass 17, in different kinds of wood from 11 to 17 times quicker than in air.

B. *Of the Strength or Intensity of Sound.*

§ 259.

The force or intensity with which the emotion of sound is excited depends on the violence of the impulse which the conducto of the sound impresses on our organs of hearing. In this view the matter, the greater or less susceptibility of the organ to a preciate sound forms no part of our inquiry. The causes whi immediately affect its intensity are the nature and size of the u dulations made by the sonorous body itself; next, the natur the medium through which the sound is transmitted; and las the distance of the sonorous body.

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that the very violent
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battle of Jena was hear
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ness. So also it is said
of Antwerp, in 1832, was
are about 370 miles distan
When the air is calm an
audible at 8000 paces; the
heard on a still night, at fr
dron of cavalry at foot pace,
ping at 1080 paces distant;
foot-pace, is audible at a dis
or gallop, at 1000 paces. —
open air, at an ordinary temp
of 230 paces, and Captain Pa
regions a conversation may be
persons a mile (?) apart.

§ 264.

The progress of sound is
as it travels in

Blows struck on a diving-bell 30 feet below water may b distinctly heard at the surface, but a sound immediatel above the water will not be audible to persons within th bell. A noise in the open air is plainly heard in a room i the window be open. The striking of a clock is rendere less loud by covering the clock with a glass shade or an similar body.—To march unobserved by the enemy the fee of the horses are sometimes wrapped in straw and rags, s as to check the propagation of sound.

C. *Phenomena arising from the Reflection of Sound.*

§ 265.

When the waves of air on which sound is being borne, impinge in the course of their expansion, on any objects by which thei advance is stopped, the particles of air recoil from such objects agreeably to the laws regulating the impact of elastic bodie (§ 213.); their return is made with equal velocity and under a equal but opposite angle, to that under which they advanced.

To this subject are applicable the laws developed in § 227. as regulating the undulations of elastic fluids.

§ 266.

If the wave of sound fall perpendicularly on the wall whence i is reflected, it returns in the same direction, and arrives again a the spot from which it originated.

If the place whence the sound arose is not far from that a which the wave is reflected, as, for example, in a room, hall, o church, it happens, in consequence of the velocity with whic sound travels, that the returning wave is generated immediatel after the original wave, and the ear becomes sensible of bot simultaneously; by this means the sound is both prolonged an rendered more loud; it frequently also makes it difficult to hea words and notes distinctly.

An *Echo* is produced when the ear is able to distinguish th original sound from its reflexion: a good ear will perceive clearl about 9 sounds in a second; *i. e.* the sounds must succeed eac other at intervals of $\frac{1}{9}$th of a second in order to be heard singly. The sound and the echo are therefore to be regarded as successiv sounds, of which the latter will be plainly heard if it fall upon th ear after that organ has formed a distinct perception of the former. The least distance at which this is possible will be that which th wave of sound can traverse, so as to impinge on the resisting body and return thence as a reflected wave in $\frac{1}{9}$th of a second of time. Now as *sound, at its* mean rate of 1120 feet, will travel about 1

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